MILK *and* dairy products *in* human nutrition

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Preface

Billions of people around the world consume milk and dairy products every day. Not only are milk and dairy products a vital source of nutrition for these people, they also present livelihoods opportunities for farmers, processors, shopkeepers and other stakeholders in the dairy value chain. But to achieve this, consumers, industry and governments need up-to-date information on how milk and dairy products can contribute to human nutrition and how dairying and dairy-industry development can best contribute to increasing food security and alleviating poverty.

This publication is unique in drawing together this information on nutrition, dairying and dairy-industry development from a wide range of sources and exploring the linkages among them. It is the result of collaboration between the Agriculture and Consumer Protection and the Economic and Social Development Departments of the Food and Agriculture Organization of the United Nations (FAO). The Nutrition Division of FAO's Economic and Social Development Department and the Rural Infrastructure and Agro-Industries Division of the Agriculture and Consumer Protection Department jointly led and coordinated the planning, preparation and publication process.

In producing this publication our aims were to:

- provide an in-depth look at selected topics of concern regarding dairy and nutrition, from milk production to consumption;
- provide a balanced and unbiased scientific overview of the impact of milk and dairy consumption on human nutrition and health in developed and developing countries; and
- give insights on dairy's potential to improve the diets of poor and undernourished people and implications for future actions by diverse stakeholders.

Many experts and scientists from around the world, from disciplines such as nutrition and food science, food safety, dairy-industry development, economics and agriculture, contributed to writing and reviewing the information and scientific knowledge presented in this publication. Each chapter has been peer reviewed by at least four independent experts to ensure that the information provided is verifiable and of good quality.

The technical editorial team thanks all who gave so generously of their expertise, time and energy.

Ellen Muehlhoff
Anthony Bennett
Deirdre McMahon

Foreword

FAO is pleased to present its new book on *Milk and Dairy Products in Human Nutrition*.

This book comes at an opportune time of renewed interest in agriculture and sustainable food-based solutions as a key strategy for improving diets and bringing greater nutritional benefits to poor and malnourished people.

In 1959, the Food and Agriculture Organization of the United Nations (FAO) produced *Milk and Milk Products in Human Nutrition*, a seminal treatise on the topic. In response to popular demand, a revised second edition was produced in 1972. Half a century after the first publication, in 2009, it was time to revisit the role of milk and dairy products in human nutrition and development.

With rising incomes and increased production, milk and dairy produce have become an important part of the diet in some parts of the world where little or no milk was consumed in the 1970s. Consumption of milk and dairy products is growing fastest in Asia and the Latin America and Caribbean region. India has recently become the world's largest milk producer, yet per capita consumption levels there are still low. Globally, too many poor people are still not able to afford a better diet and greater efforts, including agricultural growth, diversification and public investment, are needed to ensure that poor and undernourished people can acquire food that is adequate in quantity (dietary energy) and in quality (diversity, nutrient content and food safety).

FAO, in pursuing its mission of eradicating hunger and improving food security and nutrition for all, seeks to improve awareness among consumers and member governments of the importance of a balanced, healthy and sustainable diet. Our role as a global knowledge centre is to provide sound advice to member countries on the role and value of various foods from production to consumption and their role in human nutrition and health.

The publication comprises nine chapters that can either be read from start to finish for a full appreciation of the connections between dairy and human nutrition, or by topic and area of interest. The book presents information on the nutritional value of milk and dairy products and evaluates current scientific knowledge on the benefits and risks of consuming milk and dairy products in the context of global changes in diets. It highlights positive effects that connect dairy agriculture, nutrition and health at the local, national and global levels, and identifies gaps in current knowledge in these areas. It reviews global trends in milk production and consumption, discusses challenges for sustainable and inclusive dairy-industry development and food safety, reviews programmatic experiences and lessons learned about food-based solutions to problems of malnutrition and provides concrete options for governments, international organizations and the private sector. Each chapter provides a comprehensive set of references allowing the reader to probe the topics further.

The publication serves a variety of audiences, from academia to research, policy-makers and planners, the private sector and the consumer. I hope that the information presented will encourage dialogue and action within and between the sectors to achieve our common goals of reducing poverty, strengthening livelihoods and improving human nutrition and health on a sustainable basis. This way we will be taking another step in the direction of meeting the Zero Hunger Challenge earmarked by the UN Secretary-General at the Rio+20 Sustainable Development Summit in June 2012.

Daniel J. Gustafson
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Abbreviations and acronyms

ADI	acceptable daily intake
AGEs	advanced glycation end products
ALA	alpha-linolenic acid
APHCA	Animal Production and Health Commission for Asia and the Pacific
ASF	animal-source food
BMD	bone mineral density
BMI	body mass index
BPA	bisphenol A
bTB	bovine tuberculosis
CFC	Common Fund for Commodities
CHD	coronary heart disease
CI	confidence interval
CLA	conjugated linoleic acid
CMA	cow-milk allergy
CSB	corn–soy blend
CUP	Continuous Update Project
CVD	cardiovascular disease
DASH	Dietary Approaches to Stop Hypertension
DDP	dairy development project
DGDP	Dairy Goat Development Project
DHA	docosahexaenoic acid
DIDP	dairy industry development programme
DRACMA	Diagnosis and Rationale for Action against Cow's Milk Allergy
EADD	East Africa Dairy Development project
EARO	Ethiopian Agricultural Research Organization
EC	European Commission
EFSA	European Food Safety Authority
EPA	eicosapentaenoic acid
EPIC	European Prospective Investigation into Cancer and Nutrition
EU	European Union
FA	fatty acid
FDA	Food and Drug Administration (United States)
FDM	fat in dry matter

FPCM	fat and protein-corrected milk
GDP	gross domestic product
GHG	greenhouse gas
GI	glycaemic index
GMP	good manufacturing practices
GVP	good veterinary practices
HAZ	height-for-age Z-score
HDL	high-density lipoprotein
HFP	Homestead Food Production programme (Helen Keller International)
HIV	human immunodeficiency virus
HKI	Helen Keller International
HR	hazard ratio
IDF	International Dairy Federation
IgE	immunoglobulin E
IFPRI	International Food Policy Research Institute
IGF-1	insulin-like growth factor-1
IHD	ischaemic heart disease
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
iTFA	industrial *trans* fatty acid
IU	international units
JECFA	Joint FAO/WHO Expert Committee on Food Additives
KCC	Kenya Cooperative Creameries
LAB	lactic acid bacteria
LAC	Latin America and the Caribbean
LA	linoleic acid
LC-PUFA	long-chain polyunsaturated fatty acids
LDL	low-density lipoprotein
LME	liquid milk equivalent
LNP	lactase non-persistance
LNS	lipid-based nutrient supplement
LP	lactoperoxidase system
MetS	metabolic syndrome
MDG	Millennium Development Goal
MFFB	percentage moisture on a fat-free basis
MRL	maximum residue limit
MUAC	mid-upper arm circumference
MUFA	monounsaturated fatty acid
NCDs	non-communicable diseases

NGO	non-governmental organization
NHANES	National Health and Nutrition Examination Survey (United States)
NRA	nominal rate of assistance
OECD	Organisation for Economic Co-operation and Development
PBM	peak bone mass
PCBs	polychlorinated biphenyls
PDCAAS	protein-digestibility-corrected amino acid score
PHVOs	partially-hydrogenated vegetable oils
PUFA	polyunsaturated fatty acid
Rbst	recombinant bovine somatotropin
RCT	randomized controlled trial
RDA	recommended daily allowance
REACH	Renewed Efforts Against Child Hunger
RNI	recommended nutrient intake
RR	relative risk
rTFA	ruminant *trans* fatty acid
RUSF	ready-to-use supplemental food
RUTF	ready-to-use therapeutic food
SD	standard deviation
SES	socio-economic status
SFA	saturated fatty acid
STEC	Shiga toxin-producing *E. coli*
SUN	Scaling-up Nutrition
T2DM	type 2 diabetes mellitus
TB	tuberculosis
TFA	*trans* fatty acids
UHT	ultra high temperature
UK	United Kingdom
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UNSCN	United Nations Standing Committee on Nutrition
USA	United States of America
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
UV	ultraviolet
WCRF	World Cancer Research Fund
WFP	World Food Programme
WHZ	weight-for-height Z-score
WHO	World Health Organization

Contributors

Anthony Bennett joined the Food and Agriculture Organization of the United Nations (FAO) in 1995. He has worked extensively in Asia and Africa in the design and implementation of dairy-industry programmes, mainly for FAO and the International Fund for Agricultural Development (IFAD). Major work areas that he has been involved with include supporting countries in dairy-industry strategy, enhancing the inclusiveness of dairy-industry programmes and projects and promoting and enhanced investments to optimise food security, income generation and sustainable dairy-enterprise development. Mr Bennett has over 16 years of international professional experience and is the technical editor and co-author of a number of publications on issues in the dairy industry, ranging from milk safety to dairy institutions. He holds an M.Sc. Agriculture in Engineering Technology from University College Dublin, Ireland, and an M.A. from Trinity College Dublin, Ireland.

Barbara Burlingame is a nutrition scientist and Deputy Director in the Nutrition Division of FAO. She obtained her undergraduate degrees from the University of California, Davis, United States, in nutrition science and environmental toxicology, and her Ph.D. from Massey University in New Zealand. Her expertise includes food composition, human nutrient requirements and dietary assessment. Recently, her efforts have been directed toward elaborating the role of biodiversity for food and nutrition and developing models and indicators for sustainable diets.

Brian Dugdill was raised on his family's dairy farm in the north of England. Since graduating in dairying from the University of Reading in 1966 he has been a dairy practitioner, initially with Glaxo International and the United Kingdom supermarket group Asda. Since the mid-1970s he has worked in more than 30 mainly developing countries including Eritrea, Iraq, Mongolia, Myanmar and the Democratic People's Republic of Korea. From 1976 to 1985 he led the United Nations (UN)/FAO Milk Vita programme that established modern dairying in Bangladesh after its war of independence. From 1986 to 1992 he led the multidonor UN team that supported the rebuilding of the Ugandan dairy industry after its prolonged civil war. He was awarded FAO's B.R. Sen Prize for 2006 (for outstanding achievement/innovative dairy value chain approach in rebuilding the Mongolian dairy industry) and the President of Mongolia's Special Achievement Medal in 2007. He presently combines the role of Chief Adviser, East Africa Dairy Development project, with food security/nutrition and livestock assignments for the UN and others around the globe.

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Mary Kenny is Food Safety and Quality Officer in the Food Safety and Codex Unit of FAO. She currently contributes to FAO's programme of work to develop national capacities to build robust food-safety systems based on scientific principles. Previously, she was a member of the FAO team working on the provision of scientific advice for food safety. Her work involves regular contact with food-safety officials in various countries and in UN and other organizations, and with colleagues in standard-setting bodies, including Codex Alimentarius. Before joining FAO, she worked in national food safety regulatory controls in Ireland and the UK. Ms Kenny holds an M.Sc. in Food Science and Technology from University College Cork, Ireland.

Anni McLeod is a consultant in livestock policy and organizational management. She spent seven years as Senior Officer (Livestock Policy) in the Animal Production and Health Division of FAO where she contributed to the *State of Food and Agriculture 2009 –Livestock in the Balance* (FAO) and the book *Livestock in a Changing Landscape, Volume 1: Drivers, Consequences, and Responses* (Island Press) and edited the divisional publication *Livestock in Food Security*. Before joining FAO in 2003 she was deputy director of the Veterinary Epidemiology and Economics Research Unit at the University of Reading and a livestock economics consultant for PAN Livestock Services Ltd. She spent four years at the Kenya Agricultural Research Institute in Nairobi, helping to expand the livestock economics programme.

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Ellen Muehlhoff is Senior Nutrition Officer in the Nutrition Division at FAO Headquarters. She heads the Division's Nutrition Education and Consumer Awareness Group. The work of this group focuses on the dissemination of unbiased up-to-date nutrition knowledge and support to policy formulation and capacity building in nutrition education and dietary promotion with the aim of creating demand for healthy and sustainable diets, while stimulating sustainable agricultural development. Ms Muehlhoff has nearly 30 years of professional experience working in Africa, Asia, Latin American, the Caribbean and the Near East in nutrition research, household food security, consumer awareness, and the development of national food and nutrition education and communication strategies. She has been with FAO for 22 years. She obtained a B.Sc. in Social Anthropology from the London School of Economics and Political Science, United Kingdom, in 1980 and an M.Sc. in Human Nutrition (Faculty of Medicine), London School of Hygiene and Tropical Medicine, United Kingdom, in 1983.

Joseph A. Phelan graduated in Dairy Science from University College Cork, Ireland, in 1958. He worked in creamery management until 1959 and then lectured in dairy and food science at Portadown Research and Training Centre in Northern Ireland. From 1965 until 1970 he was a lecturer in dairying at Loughry and Queens University Belfast and an Inspector in the Ministry of Agriculture and Food, Northern Ireland. In 1970 he joined the National Dairy Research Institute, Moorepark, Fermoy, Ireland, as a Senior Research officer and progressed to Senior Principal Research Officer and convener of research in the Chemistry, Microbiology and Technology Departments. He was also visiting lecturer and supervisor of postgraduate research in University College Cork and University College Dublin, Ireland. He joined FAO in 1986 as a Senior Officer Dairy Development, then worked as Chief of Meat and Dairy Service and in 1996–99 as Chief of an expanded Animal Production Service. Since then he has acted as consultant for FAO, the European Union, the World Bank, the United Nations Development Programme, the Indian Council of Agricultural Research and IFAD in evaluations and field projects in ten countries and has completed authors' contracts on a range of topics in food science and livestock sector development. He has more than 200 publications in technical and scientific journals.

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United States; Viva Books, India). Agricultural sustainability and globalization are his foci in a variety of international publications. His doctoral work comparing food and risk in United States and United Kingdom organic chains found a default preference for local food. Currently, his research interests include East African dairy development and organic dairy politics of smallholder pasture dairying vis-à-vis agribusiness in the United States. He grew up on a dairy farm near Lynden, Washington, United States.

Jakob Skoet is an economist with the Agricultural Development Economics Division of FAO. After a brief spell in the Danish civil service, he joined FAO as an economist in 1991. Since then he has contributed extensively to the preparation of numerous editions of *The State of Food and Agriculture*, FAO's main annual flagship publication, each edition of which provides an in-depth study of a major issue in agricultural and rural development and food security. He was co-editor of the 2009 edition of the publication, *Livestock in the Balance*, which discussed the challenges and constraints facing the global livestock sector.

Lisa Spence joined Tate & Lyle's Global Nutrition Group in May 2012 with several years of experience directing nutrition research at both the United States National Dairy Council and the American Dietetic Association, now the Academy of Nutrition and Dietetics, with a focus on clinical and practice-based research. She earned a Ph.D. and an M.S. in Nutrition Science from Purdue University, United States, along with earning her Registered Dietician credentials. During Dr Spence's tenure at the National Dairy Council she directed the Nutrition Research programme with responsibility for managing dairy-farmer-funded research and dissemination of scientific findings. While at the American Dietetic Association, Dr Spence directed practice-based nutrition/dietetic research and managed strategic planning for a member-based committee and advisory group. Dr Spence has published original research and reviews on calcium, dairy, bone health and weight management. She has served on the United States Department of Agriculture's review panels for human nutrition and obesity and childhood-obesity prevention. She has participated in several societies including serving on the board of directors for the International Society of Nutrigenetics/Nutrigenomics.

Catherine Stanton graduated from University College Cork, Ireland, with a B.Sc. (Honours) in Nutrition and Food Chemistry (1983) and an M.Sc. in Nutrition (1986). She received her Ph.D. in Biochemistry (1988) from Bournemouth University, United Kingdom. She continued her research with Johnson & Johnson UK and as postdoctoral fellow in Department of Medicine, Wake Forest, University Medical Center, Winston-Salem, NC, United States, before joining Teagasc, Ireland, in 1994. Dr Stanton is currently Principal Research Officer at Teagasc, Moorepark Food Centre, Fermoy, Co. Cork, Ireland, leading a research programme on functional foods, with emphasis on milk and fermented dairy foods, including probiotics, and their impact on human nutrition and health, and has recently been appointed Adjunct Professor in University College Cork, Ireland. She has published over 150 papers and was awarded a D.Sc. in 2010 by the National University of Ireland in recognition of her published work. She was joint recipient of the Elie Metchknoff

Award 2010 along with colleagues Paul Ross, Colin Hill, Gerald Fitzgerald, for research on the application of lactic acid bacteria (LAB) in fermented dairy products to improve health and mechanistic basis of LAB and probiotic functionality.

Connie M. Weaver is Distinguished Professor and Head of the Department of Nutrition Science at Purdue University, West Lafayette, Indiana, United States. In 2012 she received the Herbert Newby McCoy Award from Purdue University. In 2010 she was elected to membership in the Institute of Medicine of The National Academies, United States. In 2008, she became Deputy Director of the Indiana Clinical and Translational Science Institute, United States, which is funded by the National Institutes of Health (NIH). From 2000 to 2010, she was Director of the Purdue University–University of Alabama-Birmingham NIH Botanicals Research Center. Her research interests include mineral bioavailability, calcium metabolism and bone health. Dr Weaver is past-president of the American Society for Nutritional Sciences and is on the Board of Trustees of the International Life Sciences Institute, National Osteoporosis Foundation and Science Advisory Board of Pharmavite. Dr Weaver was awarded Purdue University's Outstanding Teaching Award for her contributions in teaching. Dr Weaver was appointed to the 2005 Dietary Guidelines Advisory Committee for Americans. She has published over 260 research articles. Dr Weaver received a B.Sc. and an M.Sc. in Food Science and Human Nutrition from Oregon State University, United States, and a Ph.D. in Food Science and Human Nutrition from Florida State University, United States.

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Chapter 1
Introduction

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This book focuses on the role of milk and dairy in human nutrition and development. It takes a broad view of food systems from producer to consumer and explores the linkages between dairy-industry development, food security, human nutrition and health.

This chapter provides the global nutrition context in which this book was prepared, including current trends in malnutrition, and presents an overview of the main issues and topics that are discussed.

1.1 NUTRITION AND HEALTH

Good nutrition and access to an adequate diet and health are essential for child growth and development, body maintenance and protection from both infectious and non-communicable diseases (NCDs) in adult life. Adequate nutrition and a healthy productive population are increasingly recognized not only as resulting from but also as an important prerequisite for poverty reduction and economic and social development. Improvements in family diets and children's nutritional status globally are thus imperative for achieving the Millennium Development Goals (MDGs) related to the eradication of extreme poverty and hunger (MDG 1) and increasing child survival (MDG 4). Given evidence that children's nutrition affects their health, intelligence and educational performance and their economic status in adulthood, reducing childhood malnutrition also influences achievement of the MDGs related to universal primary education, gender equality and women's empowerment, improvements of maternal health and fighting human immunodeficiency virus (HIV).

1.2 PROGRESS IN NUTRITION OUTCOMES

1.2.1 Undernourishment

The latest FAO estimates indicate that significant progress has been made in reducing undernourishment in the world during the last 20 years (FAO, IFAD and WFP, 2012). During the period 2010–12, a total of 870 million people did not have access to sufficient dietary energy and were chronically undernourished, 132 million fewer than in 1990. The vast majority of these – 852 million – live in developing countries. The results imply that the target of halving the proportion of people who suffer from hunger by 2015 (relative to the proportion suffering from hunger in 1990)

(MDG 1c) is within reach, although many challenges remain and accelerated action is needed to continue this positive trend.

1.2.2 Childhood undernutrition

While undernourishment has been declining there have also been improvements in child nutritional status as expressed by the key anthropometric indicators of child stunting, underweight, wasting and nutrition-related child mortality. Nevertheless, the rate of improvement suggest that we are unlikely to meet the United Nations' goal of halving the 1990 underweight prevalence levels on a global level or in all developing countries.

New estimates show that globally 165 million children under five years of age, or 26 percent of all children, were stunted (low height-for-age) in 2011, a 35 percent decrease from an estimated 253 million in 1990 (UNICEF, WHO and World Bank, 2012). Despite improvements, high prevalence of stunting remains a major problem, especially in Africa and South Asia where 90 percent of the world's stunted children reside. Stunting reflects the cumulative effects of poor maternal nutrition, poor diet and infections during the first two years of life. It results in slowed child growth and impedes brain development; it often goes unrecognized and is largely irreversible. Adequate dietary intake is especially critical in the period from 6 to 18 months of a child's life when a child's growth rate is high. At six months, breastmilk alone is no longer adequate to support normal growth and mental development and nutrient-rich complementary foods must be introduced, including animal-source foods.

There has also been a decline in the prevalence of underweight (low weight-for-height) globally, with an estimated 101 million children under five years of age, or 16 percent of all children, underweight in 2011, a 36 percent decrease from an estimated 159 million in 1990 (UNICEF, WHO and World Bank, 2012). Underweight was selected as the indicator to track progress towards the MDG target of reducing malnutrition by half by 2015. Children who have a low weight-for-age can either be wasted (low weight-for-height), stunted or both. Underweight is a composite indicator and may therefore be difficult to interpret.

An estimated 52 million children under five years of age were wasted in 2011, representing an 11 percent decrease from an estimated 58 million in 1990. Latest estimates show that 70 percent of the world's wasted children live in Asia, mostly in South Asia (UNICEF, WHO and World Bank, 2012). Wasting results from acute nutritional deprivation, often combined with infection, and occurs especially during periods of severe food shortages. Wasted children have a weak immune system and are at increased risk of severe acute malnutrition and death. Findings show that childhood malnutrition is an underlying cause of death in an estimated 35 percent of all deaths among children under the age of five years, indicating that continuing efforts to improve access to better quality diets and health are imperative (Black *et al.,* 2008).

1.2.3 Micronutrient malnutrition

Access to better and more diversified diets is key for combating problems of micronutrient malnutrition or "hidden hunger". Despite progress in addressing micronutrient malnutrition in some countries and regions, several billion adults and children continue to be affected by one or more nutrient deficiencies (FAO, 2011). Although

most development programmes have focused on eliminating iron, iodine and vitamin A deficiencies, many people do not have an adequate amount of other essential micronutrients such as zinc, folate and vitamin B_{12} (Burchi, Fanzo and Frison, 2011).

Progress in eliminating vitamin A deficiency, a major cause of childhood blindness and death, has been significant in eastern Asia and Central and South America but less progress has been made in sub-Saharan Africa and Central and southern Asia (FAO, IFAD and WFP, 2012). Iodine deficiency causes goitre; in its most severe form it affects the developing brain, resulting in mental retardation. Over the last 20 years iodine deficiency has declined significantly around the world largely because of the expansion of salt-iodization programmes. Iron is absolutely critical for maternal and foetal health and survival, children's brain development during the period from 6 to 24 months of age, educational performance and labour productivity. Inadequate iron in the diet, resulting from low consumption of animal-source foods (meat, poultry, fish) and/or fortified foods, is one of the main causes of the prevailing high levels of anaemia in the world. Over 30 percent of the world's population (about 2 billion people) are anaemic, mainly as a result of iron deficiency in the diet, with more than half of the women of reproductive age in Asia affected (FAO, 2011). Prevalence in children is even higher in many populations; in Africa it is estimated to be 60 percent. There has been little progress in reducing the prevalence of anaemia in the last 20 years and prevalence may even have risen in some countries (UNSCN, 2010). Zinc deficiency is increasingly recognized as a micronutrient deficiency of significant importance in developing countries, particularly because of its association with suboptimal growth and reduced immune competence in children. In children, it is associated with increased morbidity and mortality from diarrhoea; in pregnant women, zinc deficiency may result in poor foetal development and low birth weight babies. Apart from low dietary intake of zinc-rich foods, dietary deficiency may also occur as a result of zinc binding to phytates in cereal-based diets (FAO, 2011). One of the most common explanations for poor vitamin B_{12} status is low intake of animal-source foods. Typically, the diets of populations in low-income countries is low in animal-source foods and it has become apparent that many such populations have a high prevalence of deficient and marginal plasma concentrations of vitamin B_{12} (Allen, 2008). Vitamin B_{12} and folate deficiencies have been acknowledged as the most common cause of macrocytic anaemia. Additionally, poor maternal folate status is associated with serious negative health outcomes including stillbirth, low birth weight and neural tube defects (WHO, 2012a). Although there are few data on folate intakes, one would expect that folate status is poorer in populations that consume only small amounts of green leafy vegetables and legumes (Allen, 2008).

1.2.4 The double burden of malnutrition

Paradoxically, over a billion adults (20 years and older) were overweight in 2008, with half of them being obese (WHO, 2012b). Nearly 43 million children under five years of age were overweight in 2011, about 80 percent of whom live in developing countries (UNICEF, WHO and World Bank, 2012). According to the World Health Organization (WHO), obesity has doubled since 1980 (WHO, 2012c). Once considered a problem only in high-income countries, overweight and obesity are growing rapidly in many low- and middle-income countries, especially in urban

areas. Changes in dietary patterns made possible by rising incomes and increased availability of energy-dense foods together with reductions in physical activity levels are associated with this dietary transition.

While changes in diets have brought significant improvements in nutritional status, undernourishment and levels of child malnutrition have remained unacceptably high. Moreover, a growing number of developing countries are affected by the so-called double burden of malnutrition, where undernutrition and overnutrition co-exist in the same communities and families. Improvement in the diets of malnourished populations can help raise the well-being and productive capacity of both present and future generations.

1.3 LINKING AGRICULTURE AND NUTRITION

The food and financial crises of 2008 and 2009 focused governments' attention on the importance of food and nutrition security as a fundamental component of socio-economic development and political stability. This is illustrated by efforts to reform the Committee on Food Security, the creation of the High-Level Task Force on Food Security and donors' renewed interest in food and nutrition security which led to the establishment of the European Union's Food Facility, the Spanish MDG-Fund on Children, Food Security and Nutrition and the United States Agency for International Development's Feed the Future programme and the sixty-third World Health Assembly Resolution on Infant and Young Child Feeding.

The Scaling-up Nutrition (SUN)[1] Movement is calling for high-level international attention to scale-up nutrition programmes by 2015. The movement was launched in 2010 with the support of multiple partners, including governments of countries with a high burden of malnutrition, United Nations (UN) agencies, donors, non-governmental organizations, academia and the private sector, together with advocacy initiatives such as the 1000 Days partnership. UN partners such as FAO, UNICEF, World Food Programme (WFP) and WHO collaborating in the Renewed Efforts Against Child Hunger initiative (REACH)[2] and the UN Standing Committee on Nutrition (UNSCN) are committed to strengthening governance for nutrition and to revitalizing the role of nutrition at the international level. The African Regional Nutrition Strategy 2005–2015 (African Union, 2006), for example, stresses the need to emphasize nutrition as a basic input in poverty-alleviation strategies and the achievement of the MDGs.

Growing attention is also being given to the synergies between agriculture, nutrition and health. A high-level international conference on "Leveraging Agriculture for Improving Nutrition and Health" convened by the International Food Policy Research Institute in New Delhi, India, on 10–12 February 2011 sparked an important policy dialogue on the role of agriculture and how it can be energized to enhance its impact on nutrition. The conference identified the need to learn more about the potential for agriculture to work optimally for nutrition, and the implications for future policies and programmes.

[1] http://scalingupnutrition.org
[2] http://www.reachpartnership.org

UN Secretary General Ban Ki-moon launched the Zero Hunger Challenge[3] at the UN Conference on Sustainable Development (Rio +20) in Rio de Janeiro in June 2012. The Challenge aims at promoting effective policies and programmes and increased investment to achieve the following five objectives: 1) a world where everyone has access to enough nutritious food all year round; 2) no more malnutrition in pregnancy and early childhood; an end to the tragedy of childhood stunting; 3) all food systems are sustainable, everywhere; 4) greater opportunities for smallholder farmers – especially women – who produce most of the world's food so that they are empowered to double their productivity and income; and 5) cut losses of food after production, stop wasting food and consume responsibly.

There is a broad and growing consensus on the need for food and agricultural systems to contribute more effectively to improving nutrition outcomes, particularly through improvements in diets and raising consumer awareness. This book is intended to contribute to this effort.

1.3.1 The role of milk and dairy products

The rapid rise in aggregate consumption of meat and milk is propelled by millions of people with rising incomes diversifying from primarily starch-based diets into diets containing growing amounts of dairy and meat. The underlying forces driving these trends are set to continue, and the potential for increased demand for livestock products remains vast in large parts of the developing world.

Growing consumption of dairy and other livestock products is bringing important nutritional benefits to large segments of the population of developing countries, although many millions of people in developing countries are still not able to afford better-quality diets owing to the higher cost. However, the rapid growth in production and consumption of livestock products also presents risks to human and animal health, the environment and the economic viability of many poor smallholders, but may also offer opportunities for small- and medium-scale dairy industries. These issues are explored in ***Chapter 2 – Milk availability: current production and demand and medium-term outlook***.

Milk contains numerous nutrients and it makes a significant contribution to meeting the body's needs for calcium, magnesium, selenium, riboflavin, vitamin B_{12} and pantothenic acid (vitamin B_5). However, milk does not contain enough iron and folate to meet the needs of growing infants, and the low iron content is one reason animal milks are not recommended for infants younger than 12 months old. The nutrient composition of milk from various species is detailed in ***Chapter 3 – Milk and dairy product composition***, as are the factors that influence milk composition, such as stage of lactation, breed differences, number of parturitions (parity), seasonal variations, age and health of the animal, feed and management effects. The chapter also presents a brief overview of the nutrient composition of treated liquid milk and dairy products, followed by some interesting findings regarding linkages between animal milk sources and climate change.

[3] http://www.un.org/en/zerohunger

Milk and dairy products play a key role in healthy human nutrition and development throughout life, but especially in childhood, as discussed in ***Chapter 4 – Milk and dairy products as part of the diet***. However, the role of milk and dairy products in human nutrition has been increasingly questioned in recent years. Milk is a complex food containing numerous nutrients. Most of the constituents in milk do not work in isolation, but rather interact with other constituents. Often, they are involved in more than one biological process, sometimes with conflicting health effects. Thus, while milk consumption is associated with a reduced risk of NCDs such as osteoporosis and possibly colorectal cancer and type 2 diabetes, concern has been expressed about the possible association between high dairy consumption and other NCDs such as cardiovascular disease and prostate cancer. Milk fat provides a good example of this. The traditional diet–heart paradigm, developed in the 1960s and 1970s, held that consumption of fat, and saturated fat in particular, raised levels of both cholesterol as a whole and low-density-lipoprotein cholesterol, leading to coronary heart disease. Currently, many national and international authorities recommend consumption of lower-fat dairy foods. However, the scientific rationale behind this recommendation is still debated. In Chapter 4, we summarize the available evidence on the relationship between dairy consumption and health.

Social and technological developments of the past few decades have significantly influenced the variety of dairy products available. These products vary in their nutritional composition and in ***Chapter 5 – Dairy components, products and human health*** we present some of the main components that can be altered during processes such as fermentation and fortification. Dairy foods and their nutrients are not consumed in isolation and no single food can supply all essential nutrients. When investigating the relationship between dairy products and health, it is important to consider that the human diet is complex and is not defined by the inclusion or exclusion of one food, but by its totality. Balance and variety is fundamental to healthy eating. Although it is difficult to reach a firm conclusion on the health impact of individual dairy products, in general dairy can be an important part of a healthy, balanced diet. Given the diversity of dairy products with differing compositions, ideally the consumer should be aware of the product's overall nutritional profile and how it can contribute positively or negatively to the diet. Today's consumers receive nutrition information and dietary advice on dairy consumption from a variety of sources. The subject of health and nutrition claims has received considerable attention from both the industry sector and the regulators. The general consensus amongst the legislators is that the regulatory framework should protect the consumer from false information, promote fair trade and encourage innovation in the food industry that can ultimately translate into healthier lifestyles. The debate over the validity of health claims has been particularly active in Europe. To date many products claimed as being "health-enhancing" lack the scientific evidence to merit claims. These and other issues are also discussed in Chapter 5.

With growing consumer concerns for their daily consumables there is also increased awareness of safety and quality issues in milk and dairy products. As highlighted in ***Chapter 6 – Safety and quality***, ensuring the safety of milk and dairy products is important to maintaining their nutritional values, in addition to maintaining or supporting the livelihoods of dairy farmers and processors. Raw or poorly processed or handled milk and milk products can lead to cases of food-

borne illness in humans. A great deal is known about the sources of hazards and the necessary controls and preventive measures to avoid them, and these are discussed in Chapter 6. It is not always necessary to eliminate the hazard completely, but ensuring that it does not exceed an acceptable level is critical. The challenge to all food-safety policy-makers is to balance necessary mitigation and control measures with desired economic and human health outcomes whilst taking into account the diversity of milk production systems and products.

1.3.2 Dairy programmes affecting nutrition

As a concentrated source of macro- and micronutrients, milk and dairy products can play a particularly important role in human nutrition in developing countries where the diets of poor people frequently lack diversity and consumption of animal-source foods may be limited. As discussed in ***Chapter 4 – Milk and dairy products as part of the diet*** and ***Chapter 7 – Milk and dairy programmes affecting nutrition***, milk and dairy products can add much needed diversity to plant-based diets and can contribute to promoting child growth; it is frequently a vital component in specially formulated foods in therapeutic feeding of malnourished children. Milk and dairy programmes show potential to improve human nutrition worldwide. Chapter 7 systematically reviews the evidence for the effects of milk programmes on nutrition. Dairy production and agriculture programmes were found to be more effective in improving nutrition if they were targeted to women, strategies to introduce small livestock and improved breeds of cattle and sheep, and awareness-raising on the nutritional value of milk. School-based programmes were shown to improve body composition and micronutrient status, but the issues of appropriate levels of fat, added sugar and flavouring in milk need to be addressed. Evidence of the positive effects of milk was strongest from fortified-milk programmes, although issues of limited market access, cost and questionable effects on zinc nutrition remain. Finally, adding milk to blended foods has been a nutrition strategy for decades, but the effect of the milk ingredient is largely unknown. Dairy programming faces many challenges, including the need for higher-quality evaluations with cost-effectiveness analyses and consideration of the dual burden of under- and overnutrition. Dairy offers compelling opportunities, such as the prospect of simultaneously improving nutrition and reducing poverty, aided by the generally positive public perception of milk.

1.3.3 Linking dairy agriculture and nutrition

A review of global trends and production indicates a stagnating level of milk consumption in many developed countries but a growing demand in some developing countries, notably in China (see Chapter 2). Increasing demand and relatively high prices for milk and dairy products also provide an opportunity for the millions of smallholder's farmers who produce milk in developing countries to increase their livelihoods. However, their market access is often limited by weaknesses in dairy-industry development, as discussed in ***Chapter 8 – Dairy-industry development programmes: their role in food and nutrition security and poverty reduction***. In many parts of the world, milk and dairy products are highly valued and have an important role in both household food security and also in income generation. Dairy-industry projects in developing countries often have a direct benefit for

household health and nutrition, provide employment and income for the poor and can make a substantial and sustainable contribution to poverty reduction. Chapter 8 reviews experiences and highlights a market-driven approach to investments in national and dairy institutions, such as cooperatives, groups or associations, development of sustainable and integrated supply of locally available inputs and support services and ultimately providing a fair benefit for the tens of millions of smallholder farm families who produce and market their surplus milk on a daily basis.

The agriculture–nutrition linkage is elaborated in Chapters 7 and 8. However, many of the programmes examined did not measure nutrition impacts, and there is a school of thought that questions whether we need to measure such an obvious benefit as the daily provision of milk and dairy products at smallholder household level. To compensate for this lack of measurement of nutrition impacts, this publication also draws upon the field-level experiences of a host of experts in nutrition and dairy-industry development from both the public and private sectors globally. Based on this, Chapter 8 presents a series of recommendations for enhancing the design of dairy-industry programmes, including incorporating improved process and impact evaluations to examine nutrition outcomes.

A major challenge is how to ensure that smallholder farmer families can participate in and benefit from dairy-industry development. Dairying is unique in agriculture in that it provides not only daily food at the household level but also a modest but regular income for the farm family. Moreover, dairy animals can be a source of farm power and very importantly also provide manure that is used as fertilizer for crops or as fuel. Ensuring that dairy-industry programmes are inclusive of smallholders thus has significant food-security and poverty-reduction implications, and there is increasing evidence that there can be a significant benefit for women in the household in many instances.

There is increasing interest of both governments and the private sector to meet food demands locally where feasible. Producing high-quality milk and dairy products that are or will be demanded by consumers can be a challenging and complex task. Governments may need to make initial investments in the dairy sector to stimulate private-sector investments. Both public and private sectors have a key role to play in inclusive dairy-industry development and increased collaboration between the two would optimize economic and social impact of many programmes. FAO should optimize its presence and role to facilitate and encourage such collaboration.

As aptly noted in ***Chapter 9 – Human nutrition and dairy development: trends and issues***, there are many publications on dairy development and even more on human nutrition, but this book is unusual in that it examines the extent to which it is possible to make explicit connections between the two. The concluding chapter draws together the threads of the two stories, on nutrition and on dairy development, and discusses the implications of these findings for the future of the sector, particularly in developing countries. The issues and challenges posed require actions on many fronts and an integrated effort by various stakeholders.

DISCLOSURE STATEMENT

The authors declare that no conflict of interest exists in relation to the content of the article.

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Chapter 2

Milk availability: Current production and demand and medium-term outlook

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ABSTRACT

This chapter reviews trends in global production and consumption of dairy products and the drivers behind these trends. Consumption of dairy products has increased rapidly in recent decades in several parts of the developing world, driven by economic growth and rising income levels. This has been accompanied by major increases in production in several developing countries, with growth rates significantly outpacing those in developed countries. Technological change in the sector has resulted in major increases in productivity and the emergence of large-scale commercial dairy farms. However, small-scale dairy producers have remained largely at the margin of these developments. Trade in dairy products has expanded as a result of improved processing and shipping technologies. However, the bulk of dairy production is consumed domestically and does not enter international trade. The potential for further increases in dairy consumption remains significant, especially in countries where per capita consumption is still relatively low, but the rate of growth is expected to be slower than in recent decades. The rapid expansion and transformation of the global dairy sector contributes to growing threats to the environment and to human and animal health and increases pressures on the livelihoods of small-scale dairy producers. These issues require attention if the continued development of the sector is to be sustainable and socially balanced.

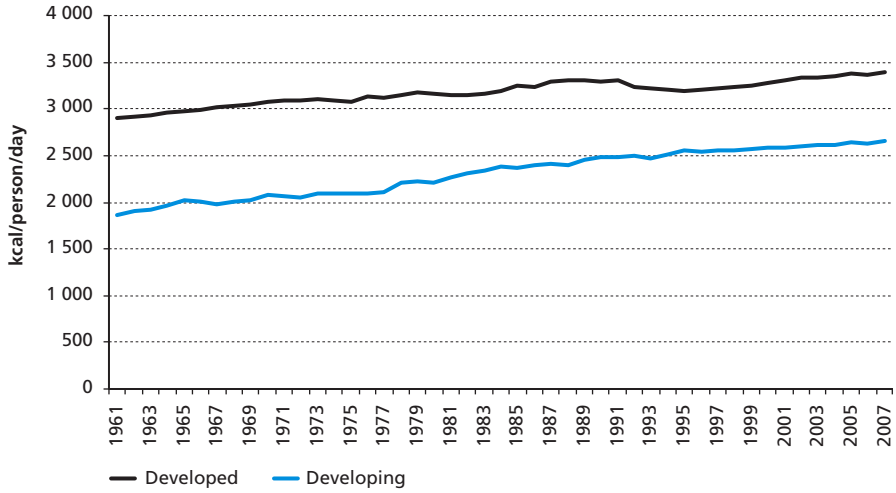
2.1 TRENDS IN FOOD CONSUMPTION PATTERNS – THE ROLE OF LIVESTOCK AND DAIRY PRODUCTS

In large parts of the developing world income growth and urbanization are leading to increasing overall food consumption and changes in dietary composition, with a growing proportion of high-value products in the diet, particularly food of animal origin.

Average per capita daily energy intake in the developing world increased from 1 861 kcal in 1961 (64 percent of the average energy intake in developed countries) to 2 651 kcal in 2007 (78 percent of the average energy intake in developed countries) (Figure 2.1).

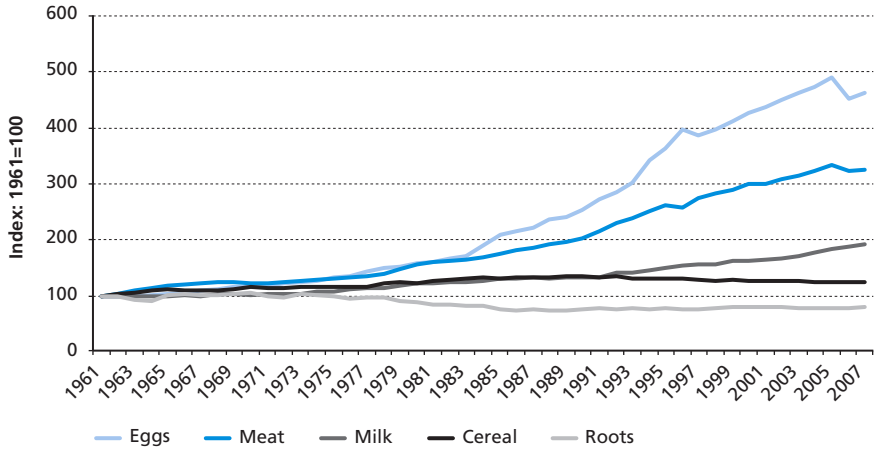
Over the same period, consumption of livestock products in developing countries increased rapidly. Milk consumption in developing countries almost doubled, meat consumption more than tripled and egg consumption increased fivefold (Figure 2.2). In contrast, consumption of roots and tubers declined slightly.

FIGURE 2.1
Per capita daily energy intake in developed and developing countries, 1961–2007 (kcal)



Source: FAOSTAT, 2011.

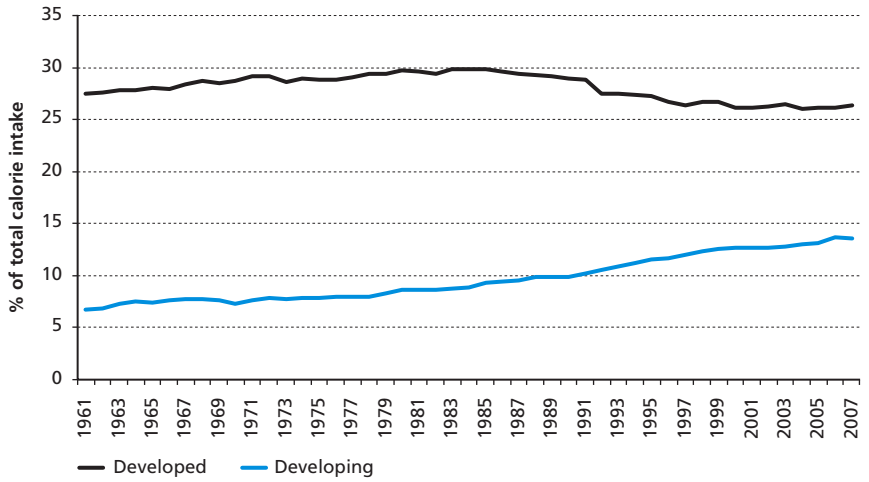
FIGURE 2.2
Per capita consumption of major food commodities in developing countries, 1961–2007 (index 1961=100)



Source: FAOSTAT, 2011.

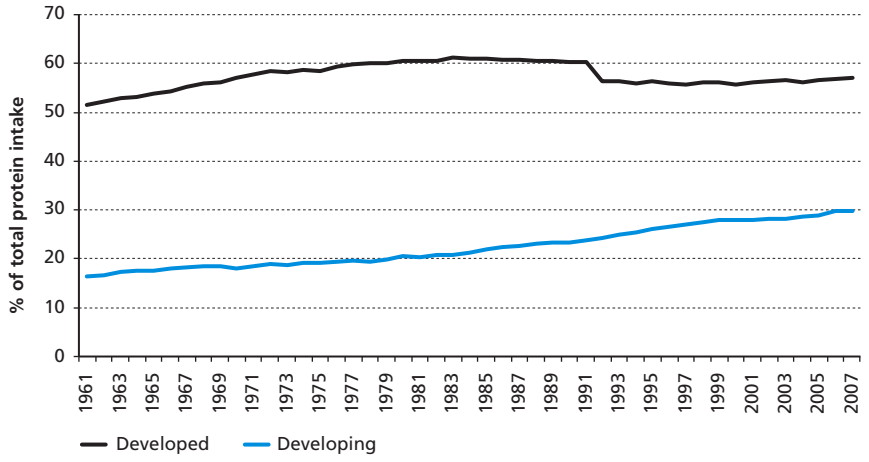
As a result of these increases in consumption of livestock products in developing countries the proportion of dietary energy and protein coming from livestock products in developing countries doubled between 1961 and 2007 (Figures 2.3 and 2.4),

FIGURE 2.3
Percentage of dietary energy derived from foods of animal origin in developed and developing countries, 1961–2007



Source: FAOSTAT, 2011.

FIGURE 2.4
Percentage of dietary protein derived from foods of animal origin in developed and developing countries, 1961–2007



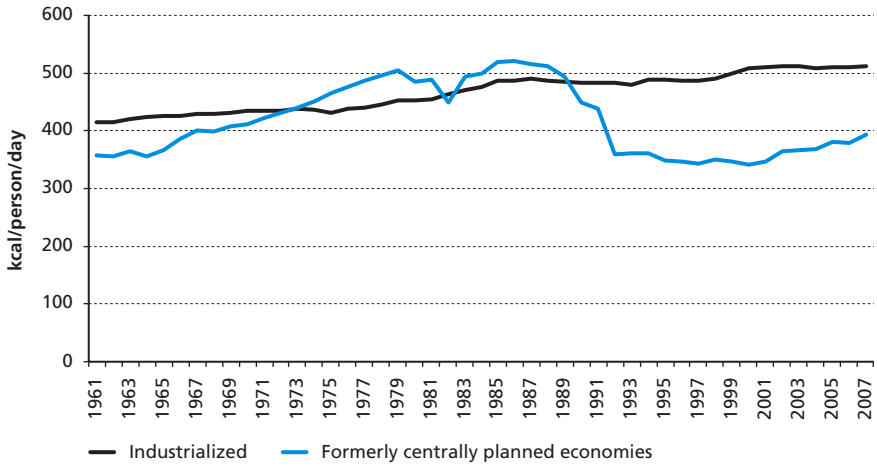
Source: FAOSTAT, 2011.

albeit to levels that are still well below those in developed countries. The declines in energy and protein intake from foods of livestock origin in the developed countries in the 1990s were largely the result of declines in consumption in the former centrally planned economies caused by elimination of subsidies, falling incomes and reduced waste in supply chains (Figure 2.5). As a result of these trends, there has been a significant narrowing in the gap between the two country groups in terms of the share of livestock in energy and protein intake.

Overall, food consumption levels and dietary patterns of developed and developing countries are converging. This applies also more specifically to dairy products, although the convergence has been slower than for livestock products in general. The percentage of total dietary energy coming from dairy products increased only slightly in developing countries, from 3.4 percent in 1961 to 4.4 percent in 2007, and was largely unchanged in developed countries over the same period (Figure 2.6). There were marked differences between regions in both the percentage of dietary energy derived from dairy products and trends (Figure 2.7). The contribution of dairy products to dietary energy intake increased in South Asia between the late 1960s and 2007, and has increased rapidly in East and Southeast Asia since 2001, albeit from a very low base. Elsewhere the contribution of dairy products to dietary energy intake has been largely static or declined.

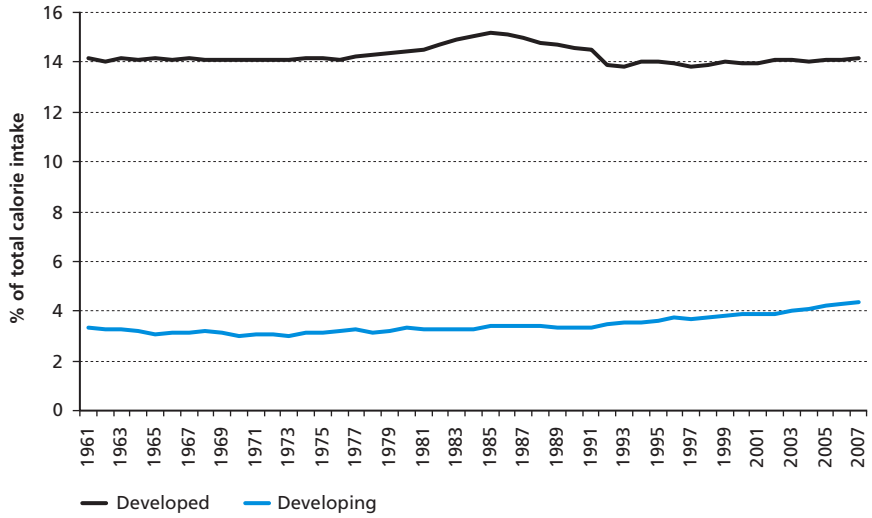
In spite of the convergence in per capita consumption of livestock products, there are still large differences between developed and developing countries, between regions and even within regions both in per capita consumption of livestock products and growth rates of consumption (Table 2.1). These differences are particularly marked in dairy products (Table 2.2).

FIGURE 2.5
Per capita energy intake from dairy products* in developed countries, 1961–2007 (kcal/year)



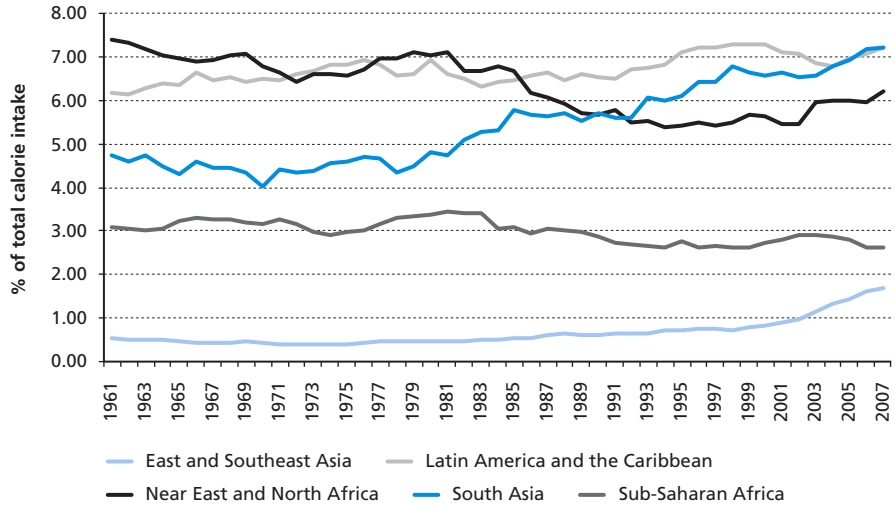
* Milk, butter and ghee, cheese.
Source: FAOSTAT, 2011.

FIGURE 2.6
Percentage of total dietary energy derived from dairy products* in developed and developing countries, 1961–2007



* Milk, butter and ghee, cheese.
Source: FAOSTAT, 2011.

FIGURE 2.7
Regional differences in percentage of total dietary energy derived from dairy products*, 1961–2007



* Milk, butter and ghee, cheese.
Source: FAOSTAT, 2011.

Between 1987 and 2007 per capita consumption of milk increased throughout the developing world, except in sub-Saharan Africa (Table 2.1). Rate of increase varied from 0.4 percent per annum in the Near East and North Africa to 9.7 percent in China, and both rates of expansion and levels of consumption differ widely. By far the highest regional consumption levels are observed in Latin America and the Caribbean (LAC). On the other hand, per caput consumption growth in the region has been relatively slow, albeit with Brazil showing a rate of growth well above the regional average. While meat consumption is growing faster than milk consumption in developing countries as a whole, milk consumption is increasing faster than meat consumption in East and Southeast Asia and South Asia (Table 2.1). Dairy products are the major source of animal protein in the diet in South Asia in particular.

TABLE 2.1
Per capita consumption of livestock primary products by region and subregion, 1987 and 2007

	Meat			Milk			Eggs		
	Per capita consumption (kg/yr)		Annual growth (%)	Per capita consumption (kg/yr)		Annual growth (%)	Per capita consumption (kg/yr)		Annual growth (%)
Region	1987	2007	1987–2007	1987	2007	1987–2007	1987	2007	1987–2007
Developed	***81.0***	***86.6***	***0.3***	***208.7***	***213.7***	***0.1***	***14.6***	***13.7***	***–0.3***
Former centrally planned economies	69.1	56.5	–1.0	182.9	179.8	–0.1	14.7	11.6	–1.2
Other developed countries	86.5	95.8	0.5	221.0	224.1	0.1	14.5	13.9	–0.2
Developing	***16.9***	***29.6***	***2.8***	***37.5***	***55.2***	***2.0***	***3.6***	***7.4***	***3.7***
East and Southeast Asia	18.4	44.7	4.6	6.4	24.9	7.0	4.5	13.6	5.6
China	20.4	53.5	4.9	4.5	28.7	9.7	4.9	17.4	6.5
Rest of East and Southeast Asia	13.6	26.6	3.4	10.7	17.0	2.4	3.7	5.8	2.3
Latin America and the Caribbean	41.8	64.1	2.2	96.1	113.3	0.8	7.5	9.5	1.2
Brazil	45.9	80.5	2.9	88.7	124.6	1.7	7.9	7.5	–0.3
Rest of Latin America	39.6	55.7	1.7	99.9	107.4	0.4	7.3	10.5	1.8
South Asia	4.7	4.6	–0.1	52.3	72.0	1.6	1.1	2.0	3.2
India	4.1	3.3	–1.1	51.0	68.7	1.5	1.1	2.1	3.4
Rest of South Asia	6.8	8.6	1.2	56.7	82.0	1.9	1.1	1.8	2.5
Near East and North Africa	21.0	28.4	1.5	80.8	87.1	0.4	4.2	6.0	1.8
Sub-Saharan Africa	13.5	14.0	0.2	31.4	30.2	–0.2	1.6	1.7	0.3
World	***32.0***	***40.3***	***1.2***	***77.9***	***84.9***	***0.4***	***6.2***	***8.6***	***1.7***

Source: Elaboration on data from FAOSTAT, 2011 for consumption and the UN for population data.

TABLE 2.2
Per capita consumption of dairy products by region and subregion, 1987 and 2007

	Butter and ghee			Cheese			Cream		
	Per capita consumption (kg/yr)		Annual growth (%)	Per capita consumption (kg/yr)		Annual growth (%)	Per capita consumption (kg/yr)		Annual growth (%)
Region	1987	2007	1987–2007	1987	2007	1987–2007	1987	2007	1987–2007
Developed	***4.6***	***2.8***	***–2.5***	***9.91***	***12.44***	***1.1***	***2.83***	***2.18***	***–1.3***
Former centrally planned economies	6.5	2.1	–5.5	7.57	6.00	–1.2	5.48	1.88	–5.2
Other developed countries	3.7	3.0	–1.1	11.14	14.43	1.3	1.46	2.16	2.0
Developing	***0.6***	***1.0***	***2.7***	***0.54***	***0.64***	***0.9***	***0.00***	***0.04***	***15.1***
East and Southeast Asia	0.1	0.1	1.8	0.11	0.24	3.8	0.00	0.02	10.2
China	0.1	0.1	2.3	0.12	0.23	3.3	0.00	0.01	0.0
Rest of East and Southeast Asia	0.2	0.2	1.2	0.10	0.26	4.9	0.01	0.03	7.0
Latin America and the Caribbean	0.7	0.5	–1.3	1.79	1.92	0.3	0.00	0.06	14.6
Brazil	0.8	0.5	–2.5	0.45	0.21	–3.7	0.00	0.00	0.0
Rest of Latin America	0.6	0.5	–0.7	2.49	2.80	0.6	0.01	0.09	14.6
South Asia	1.0	2.4	4.4	0.00	0.00				
India	1.0	2.7	5.2	0.00	0.00				
Rest of South Asia	1.2	1.6	1.6	0.01	0.01		0.00	0.00	
Near East and North Africa	2.1	1.9	–0.6	3.33	3.42	0.1	0.01	0.12	17.3
Sub-Saharan Africa	0.2	0.1	–1.1	0.31	0.34	0.4	0.00	0.05	22.4
World	***1.5***	***1.3***	***–0.8***	***2.80***	***2.86***	***0.1***	***0.85***	***0.55***	***–2.2***

Source: Elaboration on data from FAOSTAT, 2011 for consumption and the UN for population data.

Although per capita consumption of dairy products has increased rapidly in East and Southeast Asia, especially China, since 1987 the growth has started from a low base and consumption levels are still less than half the average for developing countries as a whole and less than a quarter of that in LAC (Table 2.1). Growth in dairy consumption has been limited if not stagnant over the last couple of decades in both sub-Saharan Africa and the Near East and North Africa, although in the latter region consumption levels remain relatively high.

As a result of the increase in per capita consumption of milk and other livestock products in parts of the developing world and population growth in those regions, people in developing countries are consuming an increasing share of dairy products

BOX 2.1

Differences in patterns of dairy production and consumption in China: north–south, urban–rural

Per capita consumption of dairy products is increasing rapidly in China, but is still low compared with other developing countries and developed countries in particular (Wang and Li, 2008). Since 2000, the government has put in place a set of policies to promote dairy production and technology development, supported by considerable investment. However, the rapid growth of the sector has led to new challenges and overwhelmed monitoring and control measures, as illustrated by the melamine scandal in 2008 (APHCA, 2009; Pei *et al.*, 2011).

Traditionally, Chinese diets were primarily plant based; milk and dairy products were not commonly consumed and were perceived as therapeutic food for the elderly, the infirm and the young. Economic growth and urbanization, along with the more sophisticated marketing channels that have accompanied these trends, have led to significant changes in dietary patterns, and milk and other dairy products are slowly being incorporated into the diet. Current government guidelines that recommend regular milk consumption have further challenged traditional preferences (Fuller *et al.*, 2005; Dong and Fuller, 2007). Fuller *et al*. (2006) reported that milk consumption doubled between 1996 and 2003 in households in the lowest 10 percent of the income distribution.

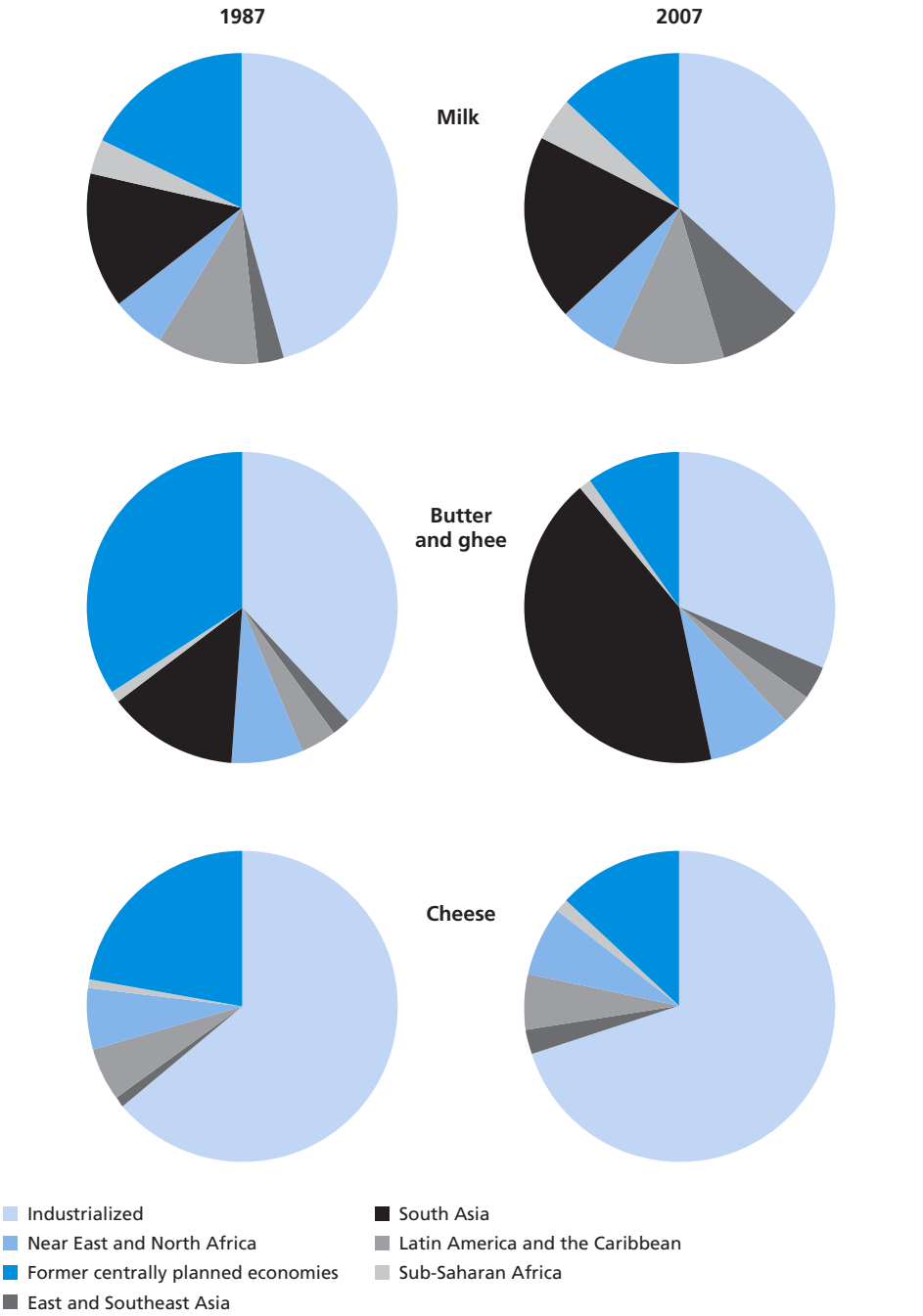
There are major differences in milk consumption and production between rural and urban areas, as well as between regions. Milk consumption is much higher in urban areas than in rural areas: for example, Fuller *et al*. (2005) reported that a "typical" rural resident consumed 2.5 kg of milk in 1990, compared with 7.5 kg for their urban counterpart. In part this is because intensive production operations are more common near large cities such as Beijing and Shanghai, thus increasing availability in these urban areas (Yang, Macaulay and Shen, 2004). The apparently low level of milk consumption in rural areas may also be the result of unrecorded home-consumption of milk (Ma *et al*., 2004; Wang, Zhou and Shen, 2008).

Regional variations in production and consumption may be attributed in part to historical differences and cultural preferences (Shono, Suzuki and Kaiser, 2000). Approximately 85 percent of China's milk is produced in northern China, which has the best climate for dairying and greatest feed availability (Wang, Zhou and Shen, 2008). However, 60 percent of the human population live in the south of the country, creating difficulties in matching supply and demand.

Source: APHCA, 2009; Dong and Fuller, 2007; Fuller *et al.*, 2005; Fuller *et al.*, 2006; Ma *et al.*, 2004; Pei *et al.*, 2011; Shono, Suzuki and Kaiser, 2000; Wang and Li, 2008; Wang, Zhou and Shen, 2008; Yang, Macaulay and Shen, 2004.

(Figure 2.8). The increase is greatest in East and Southeast Asia and South Asia, and is particularly marked in the case of butter and ghee: in 2007 South Asia accounted for around 40 percent of total consumption of butter and ghee, up from less than 20 percent in 1987.

FIGURE 2.8
Regional shares of total dairy consumption, 1987 and 2007



Source: FAOSTAT, 2011.

2.2 DRIVERS OF INCREASING CONSUMPTION OF MILK AND LIVESTOCK PRODUCTS

Levels of per capita consumption of dairy and other livestock products are determined by a number of factors, including economic factors such as income levels and relative prices, demographic factors such as urbanization, and social and cultural factors. Economic growth and rising incomes have been driving growing consumption of livestock products in much of the developing world.

Indeed, dairy and other livestock products have a high income-elasticity of demand, especially at low income levels (Table 2.3). This means that a small increase in income leads to a large increase in expenditures on livestock products. Dairy products, in particular, have higher income elasticities of demand than most other food items, including meat and fish. In other words, as incomes increase, expenditures on dairy products will grow more rapidly in percentage terms than most other food items. Furthermore, the elasticities of demand for all food categories, including dairy products, decline with rising income levels. Growth in consumption of dairy products is therefore expected to react strongly to increases in income especially in low- and middle-income countries.

This is also illustrated by plotting per capita income against per capita dietary energy intake from dairy products across countries (Figure 2.9). However, the significant dispersion in the observations around the trend line indicates that other factors play a role in determining consumption levels.

Urbanization significantly affects patterns of consumption of livestock products. In cities, people typically consume more food away from home and eat larger

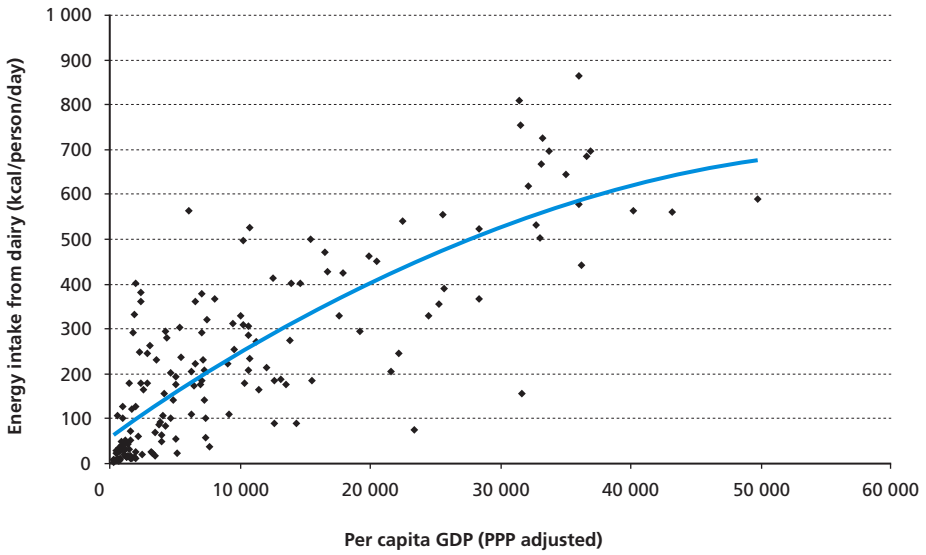
TABLE 2.3
Average income elasticities for various food categories across 144 countries in 2005

	Low-income countries (N=28)	Lower middle-income countries (N=36)	Middle-income countries (N=36)	High-income countries (N=44)
Food beverages and tobacco	0.81	0.77	0.70	0.54
Beverages and tobacco	1.73	1.13	0.92	0.67
Cereals	0.59	0.49	0.34	0.08
Meat	0.80	0.76	0.69	0.53
Dairy	0.83	0.79	0.72	0.55
Fish	0.69	0.64	0.56	0.42
Fats, oils	0.60	0.50	0.37	0.15
Fruits	0.66	0.60	0.51	0.36
Other foods	1.82	1.23	0.98	0.70

Note: The income elasticity estimates the percentage increase in expenditure on the food category resulting from a one percent increase in income. The numbers reported are simple unweighted averages of estimates for the individual countries included in each income group.

Source: Authors' calculations based on data by the USDA Economic Research Service (http://www.ers.usda.gov/data-products/commodity-and-food-elasticities.aspx).

FIGURE 2.9
Per capita income and dietary energy intake from dairy, various countries, 2007



Note: GDP per capita is measured at purchasing power parity (PPP) in constant 2005 international US$.
Source: FAOSTAT, 2011 for per capita dairy consumption and the World Bank for per capita GDP.

amounts of precooked, fast and convenience foods (Rae, 1998; King, Tityen and Vickner, 2000; Schmidhuber and Shetty, 2005). Rae (1998) found that urbanization significantly increased demand for animal products in a sample of East Asian economies, independently of income levels.

While purchasing power and urbanization explain much of the change in per capita consumption, other factors – including social and cultural ones – can have a large influence locally. For example, Brazil and Thailand have similar income per capita and urbanization rates but per capita animal product consumption is roughly twice as high in Brazil as in Thailand. Japan consumes significantly less livestock products per capita than other countries at comparable income levels. In South Asia per capita consumption of meat is lower than income alone would explain, largely for religious and cultural reasons (Rae and Nayga, 2010).

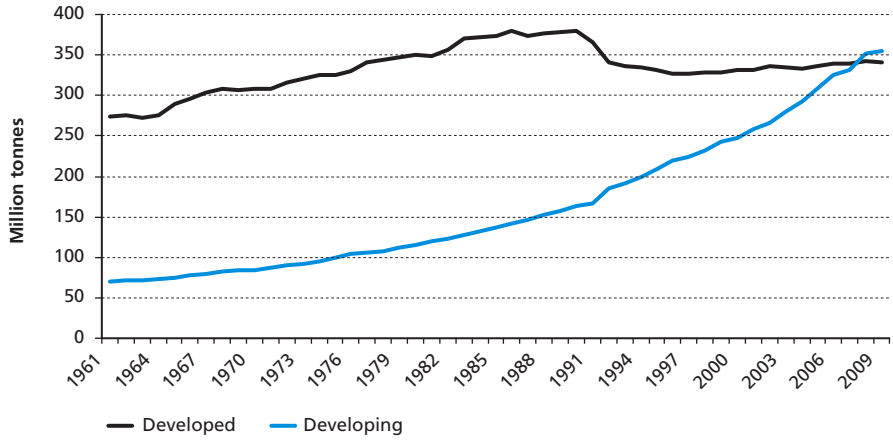
Natural resource endowment also indirectly affects consumption, as it influences the relative costs and prices of food commodities. Access to marine resources, on the one hand, and to natural resources for livestock production, on the other, influence consumption trends in opposite directions. What may be perceived as lactose intolerance limits milk consumption in Asia in particular (Dong, 2006).[4]

[4] See Chapter 4 for a further discussion.

2.3 TRENDS IN MILK PRODUCTION PATTERNS

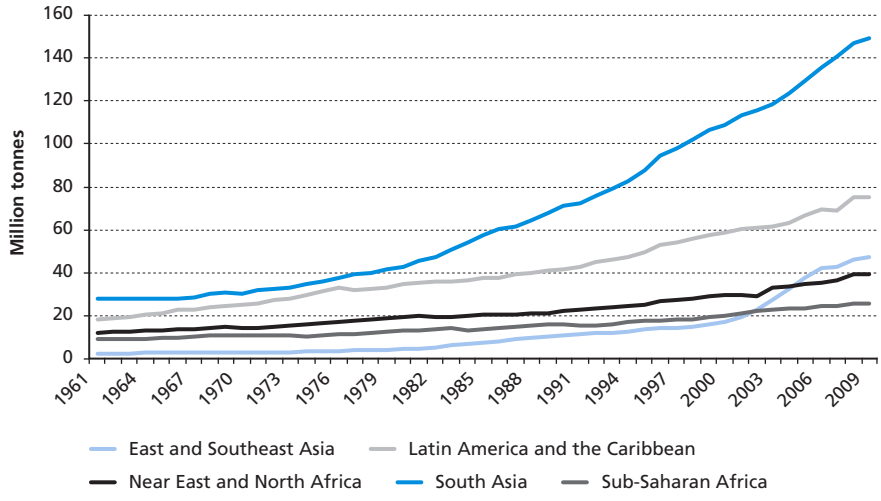
Developing country growth in demand for and consumption of milk has been matched by increasing production. Growth in milk production in developing countries has significantly outpaced that in developed countries since the 1980s (Figure 2.10). Production fell sharply in the former centrally planned economies at

FIGURE 2.10
World milk production, 1961–2009 (million tonnes)



Source: FAOSTAT, 2011.

FIGURE 2.11
Milk production in developing country regions, 1961–2009



Source: FAOSTAT, 2011.

the beginning of the transition process in the early 1990s, while production in the rest of the developed world has grown only slowly since then.

However, growth in milk production varies markedly between regions (Figure 2.11 and Table 2.4). Growth has been greatest in South Asia, which has seen continuous and sustained growth in production since the early 1970s. Today, India is responsible for almost a third of developing country production and 16 percent of global production. Production grew rapidly in East and Southeast Asia, primarily China, between 2002 and 2007 but has since slowed.

Globally, cow milk accounts for 83 percent of global production and at least 80 percent of total production in all regions except South Asia, where its share is less than half (42 percent) (Table 2.5) and sub-Saharan Africa, where it accounts for three-quarters of production. In addition to cow milk, only buffalo milk makes a substantial contribution at the global level accounting for 13 percent of global production and 24 percent of developing country production. The contribution of milk from goats (2.4 percent), sheep (1.4 percent) and camels (0.3 percent) is limited at the global level and only slightly higher among the developing countries as a group.

TABLE 2.4
Milk production by region, 1990–2010

	Milk		
	Million tonnes		Annual growth (%)
Region	1990	2010	1990–2010
Developed countries	***379.2***	***342.6***	***-0.5***
Former centrally planned economies	145.6	101.2	-1.7
Other developed countries	234.6	261.1	0.5
Developing countries	***163.1***	***380.5***	***4.1***
East and Southeast Asia	10.6	47.6	7.4
China	6.8	41.2	8.9
Rest of East and Southeast Asia	3.8	6.4	2.6
Latin America and the Caribbean	41.4	79.8	3.2
Brazil	15.1	30.9	3.5
Rest of Latin America	26.3	48.9	3.0
South Asia	71.2	162.5	4.0
India	53.7	121.8	4.0
Rest of South Asia	17.5	40.7	4.1
Near East and North Africa	22.1	40.5	2.9
Sub-Saharan Africa	16.2	29.6	2.9
World	***542.3***	***723.1***	***1.4***

Source: FAOSTAT, 2012.

BOX 2.2

Milk production increases in India but consumption remains low and malnutrition remains high

The evolution of dairy production in India is widely regarded as a success story with small-scale dairy farms as fundamental to the dairy agricultural system (FAO, 2009). Coinciding with the fourfold increase in milk production between 1963 and 2003, the average herd size decreased and the number of farms engaged in milk production increased by 40 percent (FAO, 2009). Governmental programmes, namely "Operation Flood" has driven dairy agriculture. Unfortunately, the growth in production has not translated into increased access to and consumption of dairy products by all strata of society.

Evaluating the nutritional impact of dairy production on the national population is not easy. Economic growth has increased demand for food of animal origin, with dairy products as the preferred choice in a population that is predominantly vegetarian (FAO, 2009; Gandhi and Zhou, 2010). Among dairy products, liquid milk accounts for 93.7 percent of demand for dairy products in rural areas and 88 percent in urban regions, followed by ghee (4.1 percent in rural and 7.9 percent in urban areas) (Gandhi and Zhou, 2010). Milk consumption also varies greatly between regions, from 146.2 litres per capita in Haryana and Punjab to 2.5 litres per capita in Manipur (Gandhi and Zhou, 2010).

To what degree dairy production has affected nutritional status, particularly among poorer and more vulnerable sectors of society, has not been explored, as figures for consumption of own production are difficult to obtain. However, National Nutrition Monitoring Bureau (NNMB) surveys between 1977 and 1996 showed little improvement in the nutritional status of children in spite of the nation's economic progress (Rao, Ladusingh and Pritamjit 2004). The National Family Health Survey (2005–06) found that 46 percent of children less than five years old are moderately to severely underweight, 19 percent are moderately to severely wasted and 38 percent are moderately to severely stunted (IIPS and Macro International, 2007; Arnold *et al.*, 2009; Kanjilal *et al.*, 2010). Stunting is 28 percent higher in rural areas than in urban areas, and rural children are almost 40 percent more likely to be underweight than those in urban areas. However, income poverty is not the only factor causing nutritional deficiencies, as these also occur in economically better-off households. This suggests that weak nutrition education may be an issue. Calcium intakes have decreased in spite of increases in dairy production and per capita consumption (Venkaiah *et al.*, 2002; Harinarayan *et al.*, 2007; Puri *et al.*, 2008; Wang and Li, 2008). Malhotra and Mithal (2008) reported that osteoporotic fractures are becoming increasingly prevalent in the Indian population.

Some studies point to both gender and economic inequality as underlying factors of malnutrition. Sanwalka *et al*. (2010) reported that adolescents from lower economic groups had a lower median calcium intake than those from higher income groups who consumed more dairy products; girls from both economic groups had less access to dairy products than did boys. Bhatia (2008) and the Indian Council of Medical Research (NIN, 2009) support this finding.

India has demonstrated success in boosting dairy production, but less so in increasing per capita consumption. The challenge remains to ensure that the most vulnerable people in society and all members of households benefit nutritionally from the increased availability of dairy products (Renuka *et al*., 2009).

Source: Arnold *et al.*, 2009; Bhatia, 2008; FAO, 2009; Gandhi and Zhou, 2010; Harinarayan *et al.*, 2007; IIPS and Macro International, 2007; Kanjilal *et al.*, 2010; Malhotra and Mithal, 2008; NIN, 2009; Puri *et al.*, 2008; Rao, Ladusingh and Pritamjit 2004; Renuka *et al.*, 2009; Sanwalka *et al.*, 2010; Venkaiah *et al.*, 2002; Wang and Li, 2008.

TABLE 2.5
Volume and share of milk production from sheep, goats, cows, camels and buffalo, 2006–09 averages

Region	Sheep		Goat		Cow		Camel		Buffalo		Total	
	Amount (1000 t)	Share (%)	Amount (1000 t)	Share (%)	Amount (1000 t)	Share (%)	Amount (1000 t)	Share (%)	Amount (1000 t)	Share (%)	Amount (1000 t)	Share (%)
Developed	***3 209***	***0.9***	***2 614***	***0.8***	***336 568***	***98.2***	***0***	***0.0***	***186***	***0.1***	***342 576***	***100***
Formerly centrally planned economies	1 123	1.1	853	0.8	99 259	98.0	1	0.0	13	0.0	101 248	100
Industrialized	2 245	0.9	1 918	0.7	256 776	98.3	0	0.0	178	0.1	261 117	100
Developing	***6 883***	***1.8***	***14 753***	***3.9***	***264 258***	***69.4***	***2 365***	***0.6***	***92 288***	***24.3***	***380 547***	***100***
East and Southeast Asia	1 871	3.9	614	1.3	41 690	87.6	17	0.0	3 394	7.1	47 586	100
China	1 724	4.2	278	0.7	36 036	87.6	13	0.0	3 100	7.5	41 150	100
Rest of East and Southeast Asia	147	2.3	336	5.2	5 654	87.9	4	0.1	294	4.6	6 435	100
Latin America and the Caribbean	41	0.1	589	0.7	79 152	99.2	0	0.0	0	0.0	79 782	100
Brazil	0	0.0	148	0.5	30 716	99.5	0	0.0	0	0.0	30 864	100
Rest of Latin America and the Caribbean	41	0.1	441	0.9	48 437	99.0	0	0.0	0	0.0	48 918	100
South Asia	88	0.1	7 908	4.9	68 761	42.3	0	0.0	85 779	52.8	162 535	100
India	0	0.0	4 594	3.8	54 903	45.1	0	0.0	62 350	51.2	121 847	100
Rest of South Asia	88	0.2	3 314	8.1	13 858	34.1	0	0.0	23 429	57.6	40 688	100
Near East and North Africa	3 054	7.5	1 647	4.1	32 507	80.2	191	0.5	3 109	7.7	40 508	100
Sub-Saharan Africa	1 661	5.6	3 731	12.6	22 069	74.5	2 152	7.3	0	0.0	29 613	100
World	***10 091***	***1.4***	***17 367***	***2.4***	***600 826***	***83.1***	***2 365***	***0.3***	***92 473***	***12.8***	***723 123***	***100***

Source: FAOSTAT, 2012.

Buffaloes are the most important source of milk in South Asia, accounting for slightly more than half (53 percent) of total production. They make a substantial contribution to total production also in East and Southeast Asia – especially China, where their share reaches 7.5 percent – and the Near East and North Africa, where it stands at 7.7 percent. Goat milk contributes only 2.4 percent of global milk production, but is relatively significant in sub-Saharan Africa, with 12.6 percent of the total, and parts of South Asia and East and Southeast Asia (excluding China). Sheep milk is important in the Near East and North Africa, with 7.5 percent of production, somewhat less important in sub-Saharan Africa (5.6 percent) and East and Southeast Asia (3.9 percent), but of marginal importance in other regions. Camel milk makes a notable contribution to production only in sub-Saharan Africa (7.3 percent), while its contribution is marginal in the Near East and North Africa and negligible in the other regions.

2.4 EFFECTS OF TECHNOLOGICAL CHANGES ON MILK PRODUCTION AND PROCESSING[5]

For the last 50 years, the dairy sector in most developed countries has shifted towards larger herds and greater annual milk production per cow. The driving force in this development has been the need to adopt technologies that require large capital investments and hence depend on larger herds to be profitable. At the same time, more feed concentrates are being used to support the higher yields. However, average herd size varies widely between countries, ranging from 4–6 cows in Bulgaria, Latvia and Lithuania and 10–12 cows in Austria and Croatia to 386 cows in New Zealand in 2010. Annual milk production per cow in 2010 ranged from 3 951 kg per cow in New Zealand to 11 667 kg in Israel (ICAR, 2012). This largely reflects differences in production systems, especially in regard to the feeding of the cows, and only to a minor extent different genetic potential of the animals. Feeding strategy has a major impact on the production obtained. The system in New Zealand is based on year-round grazing whereas in Israel the system is based on in barn feeding with energy-rich complete mixed rations.

Most developing countries have adverse conditions for milk production in the form of higher ambient temperature and/or humidity compared to countries with a developed dairy sector. This implies a harsher environment for the dairy cattle and in many cases a reduction in the expression of the full genetic potential of the cows. It is possible for dairy cows to produce similar yields under tropical conditions, but this requires efficient management and housing systems to protect against the adverse climatic environment, a condition that is normally seen in particular in large-scale production systems.

Most milk in developing countries is still produced in traditional small-scale systems with little or no mechanization or technological innovations; in Kenya, for example, the smallholder sector accounts for about 85 percent of total milk production. The main constraint to increased milk production in the smallholder sector in developing countries is poor animal management, particularly suboptimal feeding with poor forage and low levels of concentrate supplementation. Therefore, there

[5] Based on Henriksen *et al.*, 2009.

BOX 2.3

The pathway from milk production to increased consumption in Kenya

Milk production has increased fourfold in Kenya since the 1970s. However, regional variations are pronounced, and the highlands provide the best conditions for dairy farming, including a favourable climate. Small-scale dairy farms account for 85 percent of total milk production, and it is estimated that two million households are involved in dairy farming (Staal, Pratt and Jabbar, 2008; FAO, 2009). Informal marketing via small-scale agents is the main channel of milk distribution. A smaller, but well-organized, formal sector provides processed and packaged milk to urban consumers.

Consumption volume varies markedly between households depending on socio-economic factors and location. Njarui *et al.* (2010), for example, reported that in 1999 rural "milk-purchasing" households consumed 19 litres of milk per capita annually, rural "milk producing" households consumed 45 litres of milk per capita annually and urban households consumed 125 litres of milk per person annually. In urban areas, milk is rarely consumed by the poor and middle classes outside of the home because of strong competition from other beverages such as soda (TIAPD, 2005). Within the home, milk is consumed by all socio-economic strata; what differs is the type of milk. Higher income groups consume more pasteurized milk than raw milk (TIAPD, 2005). Fresh ("raw") milk is generally preferred to ultra high temperature (UHT) and pasteurized milk in coastal Kenya (Nicholson *et al.*, 2003). The preference for raw milk is generally more marked in the rural regions but is also common in urban areas (SDP, 2004). Dairy products such as cheese and ghee are consumed less frequently than milk, and consumption levels are particularly low in poorer households (Njarui *et al.*, 2010).

Source: FAO, 2009; Nicholson *et al.*, 2003; Njarui *et al.*, 2010; SDP, 2004; Staal, Pratt and Jabbar, 2008; TIAPD, 2005.

is a large potential for increasing milk yield in the smallholder sector by improving feeding and increasing concentrate supplementation (Mlay, 2001; Madsen, Weisbjerg and Hvelplund, 2007). However, local research is needed to identify the specific constraints on smallholder production systems and develop appropriate solutions as many of the mechanical and technological solutions developed for large-scale dairy farms are too costly or complex for smallholders to adopt.

The past 50 years have also seen major developments in the processing of milk. Milk is perishable and deteriorates rapidly if left at ambient temperature. Hence the major challenges have been to ensure delivery of healthy and safe dairy products of a consistent quality to an ever increasing number of consumers, as well as to provide farmers and industry with increased revenue from the milk delivered. Technological development has played an important role in meeting these challenges, mainly by providing the dairy industry with tools to reduce wastage, optimize production and maximize utilization of milk constituents.[6]

[6] This and the following three paragraphs are based on Henriksen *et al.*, 2009.

Key developments in dairy processing include cold storage of raw milk (which is probably the major single factor influencing the quality of raw milk), pasteurization, UHT treatment and sterile packaging. Other significant technological developments include membrane filtration, developments in molecular biology and molecular interactions and in enzyme technologies. Breakthroughs in packaging also have been integral to developments in dairy technology. Disposable packaging has become prevalent, and there has been a development towards composite materials specifically designed for various products. Some packaging technologies have helped extend the shelf-life of dairy products. In general, the developments in packaging materials and systems have improved protection of dairy products and helped promote the consumption of milk and dairy products (Gorski-Berry, 1999).

Driving such technological development is a major research effort by both academia and the private sector. There is now a thorough and detailed knowledge of milk constituents and their behaviour during processing and storage of products as well as a good grasp of the variations occurring and their importance. This, along with the natural molecular organization of mammalian milk, has enabled the dairy industry to preserve and manipulate milk constituents into an ever-increasing diversity of products, with much local variation and tradition still intact.

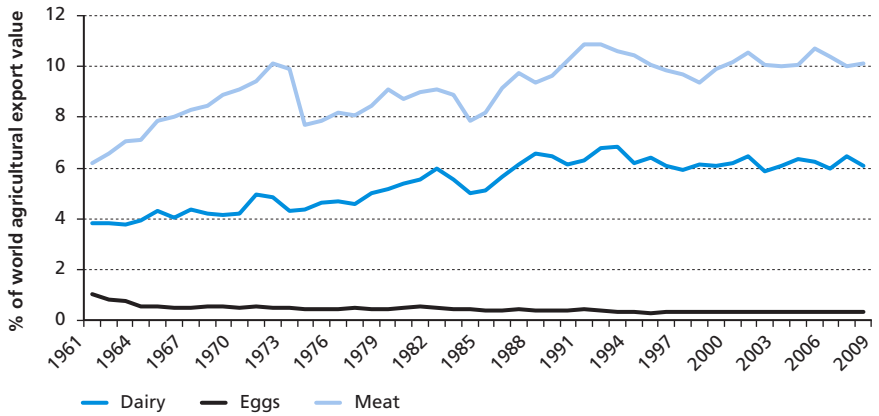
The technological development and innovation have not, of course, proceeded at the same rate everywhere. However, the increased globalization of the dairy industry as well as the concentration of the supply of ingredients or dairy processing equipment in the hands of only a few companies has reduced many regional differences. Dairy plants are developing along very similar lines and emerging technologies or novel processing aids are being applied around the world. Thus products with very similar characteristics are available in many different countries. However, there are major differences in dairy plants. Dairy processing plants in the developing world, with generally lower labour costs, use much more manual labour in the packaging departments, and hence generate much more employment.

2.5 TRENDS IN INTERNATIONAL TRADE IN LIVESTOCK PRODUCTS

Between 1961 and 2008, the relative share of livestock products (meat, dairy and eggs) in global agricultural export value increased from 11 percent to 17 percent (Figure 2.12). However, most of this trade was in meat products. In spite of the growing importance of livestock products in international agricultural trade, trade in crops still dwarfs that of livestock products.

Technological progress in processing and packaging has contributed to expansion of trade in dairy products. Between 1980 and 2008, the volume of total dairy exports (expressed in milk equivalents) more than doubled, from 41.7 million tonnes in 1980 to 92.2 million tonnes in 2008. Also the share of dairy production that entered international trade also increased, from 8.5 percent to 12.6 percent. This reflects the increasing degree of openness of the sector to trade and was also influenced by heavy use of export subsidies by developed countries. However, the share of output that is traded internationally still remains relatively low because dairy products are highly perishable and most dairy products are consumed within the country of production (Table 2.6).

FIGURE 2.12
Share of livestock products in global agricultural export value, 1961–2009



Source: FAOSTAT, 2011.

TABLE 2.6
Global trade in dairy products, 1980–2008 (in milk equivalents)

	World exports (Million tonnes)		Share of total production (Percent)		Annual growth in exports (Percent)
Product	1980	2008	1980	2008	1980–2008
Dairy*	41.7	92.2	8.5	12.6	2.9

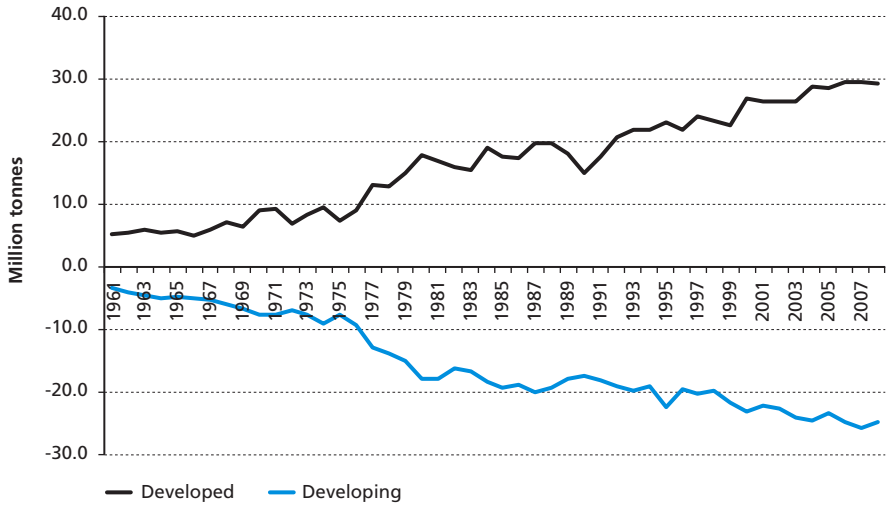
* Milk equivalent
Source: FAOSTAT, 2011.

Generally, geographic patterns of production and trade of dairy products have been significantly affected by agricultural and other economic policies in both developed and developing countries.

Typically, developed countries have tended to protect and subsidize agricultural producers through various trade and agricultural policy instruments. Milk has on average received the one of the highest levels of subsidies and protection as measured by the nominal rate of assistance (NRA). NRA is an indicator that measures the percentage by which government policies have raised gross returns to farmers above what they would have been without government intervention. However, between the beginning of the 1980s (1980–84) and the beginning of the 2000s (2000–2004) the level of subsidization of milk in the developing countries – measured by the average NRA – has declined significantly as a result of widespread agricultural policy reforms among the developed countries. However, the NRA for milk remains positive and the third highest after rice and sugar (Anderson, 2009).

Developing countries also have tended to subsidize milk producers, although to a much lesser extent than those in developed countries, and the level of subsidization declined between 1980–84 and 2000–04 (Anderson, 2009).

FIGURE 2.13
Net exports of dairy products from developed and developing countries, 1961–2008



Source: FAOSTAT, 2011.

In spite of the subsidization of the sector, the developing countries as a group are net importers of dairy products, and their dependency on imports has been increasing (Figure 2.13), reflecting the higher degree of subsidization prevailing in the developing countries. All major developing country regions are net importers of dairy products in volume terms.

2.6 FUTURE TRENDS IN PRODUCTION AND CONSUMPTION OF DAIRY PRODUCTS

The rapid growth of the livestock sector, including dairy, in large parts of the developing world has been essentially demand-driven. The factors that have encouraged growth in demand in developing countries – rising incomes, urbanization and population growth – will continue to be important over the coming decades. Population growth, although slowing, will continue. Urbanization is considered unstoppable. Income growth is generally considered the strongest driver of increased demand for dairy products. In the longer run growing incomes will continue fuelling demand growth. The effect of economic growth on demand for dairy and other livestock products depends on the rate of growth and where it occurs. Demand is more responsive to income growth in low-income countries than in higher-income countries. Overall the potential for expanding per capita consumption remains vast in large parts of the developing world as rising incomes translate into growing purchasing power (FAO, 2006) (Table 2.7). Growth in consumption and production of dairy products is expected to remain strong although slowing somewhat.

TABLE 2.7
Average annual growth rates in production and consumption of milk and dairy products, 1991–2007 (actual), 2005/07–2030 and 2005/07–2050 (projections)

Region	Production (%)			Consumption (%)		
	1991–2007	2005/07–2030	2005/07–2050	1991–2007	2005/07–2030	2005/07–2050
Developing countries	***4.2***	***2.1***	***1.8***	***3.9***	***2.1***	***1.7***
East Asia	9.5	2.2	1.5	7.9	2.2	1.5
Latin America and Caribbean	3.3	1.7	1.3	2.6	1.5	1.1
Near East and North Africa	3.1	1.9	1.7	2.8	1.9	1.6
South Asia	4.1	2.3	2.0	4.1	2.3	2.0
Sub-Saharan Africa	3.5	2.4	2.3	3.5	2.5	2.3
Developed countries	***0.0***	***0.5***	***0.3***	***-0.1***	***0.5***	***0.3***
World	***1.6***	***1.3***	***1.1***	***1.6***	***1.3***	***1.1***

Source: FAO, 2012.

As in the past, the geographic distribution of production increases will largely mirror that of consumption. Most future growth is expected to occur in developing countries, especially East Asia, South Asia and sub-Saharan Africa.

Medium-term projections for the period 2012–21 (OECD–FAO, 2012) appear in line with the longer-term trends highlighted by Table 2.7. Although the price hikes during the food-price crisis of 2007–08 and the ensuing economic crisis reduced demand and illustrated the high price and income elasticity of demand for dairy products, the Organisation for Economic Co-operation and Development (OECD) and FAO project a return to steady consumption growth driven by growing populations, rising incomes and a growing popularity of dairy products in developing countries. The strongest demand growth is expected in China and India.

According to OECD and FAO, the milk and dairy sector will remain one of the fastest-growing agricultural subsectors over the coming decade in terms of production, only exceeded by poultry meat and vegetable oils. They project global milk production will expand at an annual rate of two percent over the 2012–21 period, similar to that of the last decade (Table 2.8). Again, most of the expansion in output is projected to occur in the developing countries. All developing country regions are projected to see sustained growth in production, with the highest rates of growth in sub-Saharan Africa and India. Growth in China is projected to slow as the industry has matured. India is projected to consolidate its position as the world's largest producer, increasing its share of global production from 16.4 percent to 18.8 percent.

TABLE 2.8
Estimated (2009–11) and projected (2021) milk production, and actual (2002–11) and projected (2012–2021) rate of growth

Region	Production ('000 tonnes)		Rate of growth (%)	
	Average 2009–11 est.	2021	2002–11	2012–21
Developed countries	***362 668***	***411 426***	***0.5***	***1.2***
Developing countries	***348 893***	***468 925***	***4.0***	***2.7***
North Africa	11 377	13 832	3.9	2.0
Sub-Saharan Africa	24 340	33 298	2.5	3.1
Latin America and the Caribbean	80 260	102 838	2.9	2.1
Brazil	31 210	38 440	3.4	1.8
Asia and the Pacific	232 916	318 956	4.6	2.9
China	42 773	60 432	10.0	2.5
India	118 815	165 632	4.1	3.4
World	***711 561***	***880 350***	***2.1***	***2.0***

Source: OECD–FAO, 2012.

2.7 EMERGING ISSUES AND CHALLENGES[7]

The rapid rise in aggregate consumption of meat and milk is propelled by increasing numbers of people with rising incomes changing from primarily starch-based diets to diets containing growing amounts of dairy products and meat. The underlying forces driving this trend – primarily population and income growth and urbanization – are set to continue, and the potential for increased demand remains vast in large parts of the developing world. Consumption of moderate amounts of dairy and other livestock products has important nutritional benefits, but the rapid growth in production and consumption of livestock products also has a number of possible harmful effects:

- The expansion of livestock production increases demand for feed, increasing pressures on the land and water resources, in particular, and increases the livestock sector's impact on climate change through greenhouse gas (GHG) emissions.
- The increasing number and concentration of animals in more intensive production system increases contact between people and animals, increasing the risk of spreading diseases and the passage of disease agents between animal species and from livestock to humans.
- Intensification of livestock production may marginalize smallholders still further, with serious social implications.

[7] For further discussion of the issues highlighted in this section, see FAO, 2009.

2.7.1 Impact on the environment

Dairy production systems are important and complex sources of GHG emissions, notably of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). According to a global life cycle assessment in 2007 the dairy cattle sector emitted 1 969 million tonnes of CO_2 equivalent (CO_2-eq), of which 1 328 million tonnes were attributed to milk (FAO, 2010). Globally, milk production, processing and transportation accounted for 2.7 percent of anthropogenic GHG emissions reported by IPCC (2007) (FAO, 2010). CH_4 emissions are by far the largest contributor, accounting for about 52 percent of the total from the sector, followed by N_2O and then CO_2.

Globally, emissions per unit of milk product are estimated at 2.4 kg CO_2-eq per kg of fat and protein-corrected milk (FPCM) at the farm gate (FAO, 2010). However, values vary greatly between regions. Sub-Saharan Africa has the highest emissions per unit, with an average of 7.5 kg CO_2-eq per kg FPCM at the farm gate, but, given the low level of production, in absolute terms its emissions remain low. In the rest of the developing countries emissions per unit range from 3 to 5 kg CO_2-eq per kg FPCM at the farm gate, while in Europe and North America the corresponding values are 1–2 kg CO_2-eq per kg FPCM at the farm gate.

One possible way to reduce GHG emissions from livestock is to raise productivity through the introduction of production and management practices that increase yields, e.g. increased and improved use of inputs such as feed and related fertilizer use, genetic material, animal health inputs and energy. Extensive production systems often have limited productivity, as a large share of feed is spent on the animal's maintenance rather than on producing products or services useful to people. The result is inefficient use of resources and often high levels of environmental damage per unit of output. Improvements in livestock productivity have been shown to have resulted in local reduction in (direct) emission intensity – described as CO_2-eq per physical unit of output (European Commission, 2005; Capper, Cady and Bauman, 2009).

While contributing to climate change, the livestock sector is also affected by the degradation of ecosystems and climate change. Climate change will have far-reaching consequences for animal production through its effects on forage and range productivity, and on feed intake and feed conversion rates. The probability of extreme weather events is also likely to increase. Some of the greatest impacts of climate change are likely to be felt in grazing systems in arid and semi-arid areas, particularly at low latitudes. In non-grazing systems, which are characterized by the confinement of animals (often in climate-controlled buildings), the direct impacts of climate change are likely to be less and mostly indirect, e.g. feed, energy and water costs. Climate change is also expected to change the occurrence and spread of vector-borne diseases and animal parasites, which will have a disproportionately large impact on the most vulnerable men and women in the livestock sector (FAO, 2009).

Dairy production systems also contribute to other environmental issues, notably water resource management, through withdrawals, modification of runoff and release of pollutants. Dairy cattle require large amounts of bulky fibrous feed in their diets. Dairy herds therefore need to be close to the source of their feed, more than other forms of market-oriented livestock production. This provides good opportunities for nutrient cycling, which is beneficial to the environment. However,

excessive use of nitrogen fertilizer on dairy farms is one of the main causes of high nitrate levels in surface water in OECD countries. Manure runoff and leaching from large-scale dairy operations may also contaminate soil and water (FAO, 2009).

2.7.2 Impacts on animal and human health[8]

The increasing concentration of production and growth in trade are leading to new challenges in the management of animal diseases. Animal diseases reduce production and productivity, disrupt local and national economies, threaten human health and exacerbate poverty. The most serious health threat is that of a human pandemic. The economic threats from livestock diseases may be less dramatic, but may also exact highs cost in terms of human welfare and pose significant livelihood risks for smallholders. Humans, animals and their pathogens have coexisted for millennia, but recent economic, institutional and environmental trends are creating new disease risks and intensifying old ones. These risks are the result of a combination of rapid structural change in the sector, geographic clustering of intensive livestock production facilities near urban population centres and the movement of animals, people and pathogens between intensive and traditional production systems. At the same time, climate change is altering patterns of livestock disease incidence as pathogens and the insects and other vectors that carry them enter new ecological zones.

Animal-health and food-safety systems are also confronted with new and additional challenges as a result of the lengthening and increasing complexity of supply chains in the livestock sector, facilitated by globalization and trade liberalization. Meanwhile, increasingly stringent food-safety and animal-health regulations and private standards aimed at promoting consumer welfare are creating challenges for producers, especially smallholders, who have less technical and financial capacity to comply with them.

Many national institutions for disease control are obliged to respond to an increasing number of crises instead of focusing on principles of prevention, progressive disease containment, or elimination of a new emerging disease before it spreads. Consequently, the economic impact of diseases and the cost of control measures are high and increasing. In addition, sometimes necessary control measures such as culling may severely affect the entire production sector, and may be devastating for the poorest households for whom livestock forms a major asset and safety net.

2.7.3 Challenges for smallholder production and poverty alleviation

Livestock are important to the livelihoods of many poor people in rural areas. Growing demand for livestock products and technological changes along the food chain has spurred major changes in production systems. As a result, small-scale mixed production systems are facing increased competition from large-scale specialized production units based on purchased inputs. These trends present major competitive challenges for smallholders and have implications for the ability of the sector to contribute to poverty reduction.

[8] Based on FAO, 2009.

Despite rapid structural change in parts of the sector, smallholders still dominate production in many developing countries. Dairy production can contribute to household livelihood, food security and nutrition. Strong demand for dairy products and increasingly complex processing and marketing systems offer significant opportunities for growth and poverty reduction at every stage in the value chain. However, these new market opportunities and livelihood options are accompanied by rapidly changing patterns of competition, consumer preferences and market standards, which may undermine the ability of smallholders to remain competitive. They must therefore be carefully managed to ensure that smallholders, both women and men, are in a position to exploit opportunities in this rapidly changing sector. Policy reforms, institutional support and public and private investments are urgently needed to assist those smallholders who can compete in the new markets; to ease the transition of those who will exit the sector; and to protect the crucial safety-net function performed by livestock for the most vulnerable households (FAO, 2009).

Productivity growth in agriculture is central to economic growth, poverty reduction and food security. Decades of economic research have confirmed that agricultural productivity growth has positive effects for the poor in three areas: lower food prices for consumers; higher incomes for producers; and growth multiplier effects through the rest of the economy as demand for other goods and services increases (Alston *et al*., 2000). However, serious questions and policy challenges must be addressed if the potential of the livestock sector to promote growth and reduce poverty is to be met in a sustainable way.

2.7.4 Conclusion

In conclusion, the rapid growth of the livestock sector as a whole, and the dairy sector in particular, in a setting of weak institutions and governance has given rise to risks with potentially large negative implications for livelihoods, human and animal health and the environment. To meet the challenges and constraints it faces, the sector requires renewed attention and investments from the agricultural research and development community and robust institutional and governance mechanisms. The future contribution of dairy and livestock products to human welfare will depend also on how these issues are addressed.[9]

2.8 KEY MESSAGES

Over the past decades, per capita consumption of dairy products has grown rapidly in many, but not all, developing countries while remaining almost stagnant in the developed world. The gap in consumption levels between developed and many developing countries has narrowed.

Although per capita dairy consumption has increased over the last two decades in all regions except sub-Saharan Africa, there are large differences between developing regions in both consumption levels and consumption growth. Most of the growth in consumption of dairy products in the developing world is attributable

[9] For further discussion, see FAO, 2009.

to a few regions (e.g. South Asia) or even to single large countries, notably Brazil. China has recently experienced rapid growth in consumption of livestock products, but per capita consumption levels remain relatively low. In sub-Saharan Africa per capita consumption of dairy decreased in the last 20 years.

The most important driver of growth in consumption of dairy products in developing countries has been economic growth: the increase in per capita consumption of dairy products (as well as other livestock products) in developing countries is highly correlated with growth in per capita income. However, numerous other factors, including cultural preferences for certain livestock products, affect consumption levels in individual countries.

The combination of rising level of per capita consumption and relatively high population growth rates has resulted in a large increase in production in the developing world and a shift in the balance of production across regions. In recent decades, developing countries closed the gap with developed countries in milk production, and India emerged as the largest milk producer.

The livestock sector has been affected by deep technological changes along the food chain, both in developed countries and in many developing countries. Technological change and productivity growth has been especially rapid in the poultry, eggs, pork and dairy sectors. However, much of product of research and development has not been generally available to or directly applicable to small-scale producers in developing countries.

The reduction in transportation costs and the weakening of tariff barriers boosted agricultural trade and in particular trade in livestock products: from 1961 to 2006, the relative share of meat, dairy and eggs in global agricultural exports increased from 11 to 17 percent. The bulk of this is represented by meat, while dairy products account for around six percent of agricultural exports. Most dairy products are consumed domestically, and only about 13 percent enter international trade, although the share has been increasing.

The growth of the livestock sector is expected to slow somewhat in the coming decades as a number of factors behind the demand boom of the last 20 years begin to fade. However, growth in consumption and production of dairy products is expected to continue, especially in large parts of the developing countries where consumption levels are still low.

Rapid growth and structural change in the livestock sector are leading to increasing risks to the environment, human and animal health and of social exclusion. The future contribution of dairy and the livestock sector in general will depend on how these issues are addressed by governments and the international community.

DISCLOSURE STATEMENT

The authors declare that no financial or other conflict of interest exists in relation to the content of the chapter.

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Chapter 3

Milk and dairy product composition

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ABSTRACT

The first section of this chapter provides detailed information on the composition of animal milks used for human consumption, including milk from both major dairy species (cow, buffalo, goat and sheep) and minor species (yak, mithun, musk ox, mare, donkey, dromedary and Bactrian camels, llama, alpaca, reindeer and moose). Macro- and micronutrient contents of milks are given for the various species, mineral and vitamin contents in the milks are compared with the recommended nutrient intakes for children between one and three years old and those suitable for children who are allergic to cow milk are noted. Nutritional claims that would be permitted according to the *CODEX Guide to Food Labelling* are considered for the various milks. Interspecies differences in protein, fat and lactose contents are highlighted. The contribution of milk to dietary energy, protein and fat in various regions of the world is considered. The effects of feeding and lactation state on milk composition are considered.

The second part of the chapter presents less-detailed information on the composition of treated liquid milks and dairy products, including fermented milk products, cheese, butter and ghee, cream and whey products. The current definitions according to the FAO Classifications of Commodities/CODEX are given, together with the impact of processing on nutrient profiles. Finally, milk products from milk from underutilized species are presented.

3.1 INTRODUCTION

Domestication of animals for livestock has played a key role in the development of human civilizations. The cow[10] has now become the main dairy animal associated with milk, with the term "milk" being almost synonymous with cow milk in most people's minds. However, milk from a range of other animal species is also consumed and will therefore be covered in this chapter.

[10] Here "cow" refers to the female of *Bos taurus* and *Bos indicus* species.

The demand for milk in developing countries is expected to increase by 25 percent by 2025 (FAO, 2008a). Small-scale livestock holders supply the vast majority of this milk, and dairy animals provide household food security and a means of fast returns for them. About 180–200 million people belong to pastoral societies that raise livestock using natural rangelands as the main forage (Degen, 2007). These rangelands are in deserts, mountains and steppes – land that cannot be cultivated or used for agricultural purposes – and cover almost 25 percent of the world's land surface (Degen, 2007). Pastoralists traditionally keep more than one species of livestock in order to make the most of the rangelands, as some species are mainly grazers (e.g. sheep and cattle), while others are better browsers (e.g. goats and camels). Diversifying in this manner also reduces risk from disease or extreme environmental conditions (Degen, 2007).

The majority of papers published on milk composition relate to fat and fatty acid (FA) profiles. Milk protein is also well covered, total protein content being one of main quality criteria applied to milk payment to producers in many countries where milk is priced according to composition (others being fat and solids-non-fat) (FAO, 2004). The literature mainly deals with cow milk, followed by goat and sheep milks; buffalo milk is poorly represented, given that globally buffalo milk production is second only to cow milk. The composition of milk from minor dairy animals (animals other than cows, buffalo, goats and sheep, which contribute 0.2 percent of world milk production) has so far received little research attention. This is unfortunate, as some of them (donkey, reindeer, yak, Bactrian camel, moose, musk ox, llama, alpaca and mithun) are underutilized, that is, "species with underexploited potential for contributing to food security, health and nutrition, income generation and environmental services" (FAO, 2008b).

Knowledge of differences in nutrients in milk from various species facilitates development of products for consumers with specific needs, e.g. substitutes for cow milk for people with cow milk allergy (Park and Haenlein, 2006; Suutari *et al.*, 2006), and milks formulated for the rehabilitation of malnourished individuals and other nutritionally vulnerable groups.

In the future, the composition of milk could be tailored to meet demand within each national economy: for example, the American and Canadian markets have an oversupply of lactose, which is disposed of for minimal returns, while the British market has an unmet demand for fat and an oversupply of protein (Karatzas and Turner, 1997). Specific industrial demands could also be met, such as milk with a high casein content for the cheese industry.

There are difficulties associated with using the available literature to draw meaningful conclusions about the milk composition of different species because few studies provide detailed information on management, season, feed etc – factors that affect milk composition (see Section 3.2.3 Factors affecting milk composition). The multiplicity and variation in analytical methods (e.g. for assessing protein, fat and carbohydrate contents) can also lead to differences in results. The testing methods can also vary: some are actual research studies under controlled conditions, while others analyse data gathered from records.

In this chapter we examine the composition of milks consumed by humans that are produced by both major and minor dairy animals. The second part of the chapter focuses on current FAO definitions and classifications of milk products, together with the impact of processing on nutrient profiles. FAOSTAT definitions are given

where available, with CODEX definitions given only where FAOSTAT definitions are not available or where additional information is needed. A few case studies are included in order to highlight particular products.

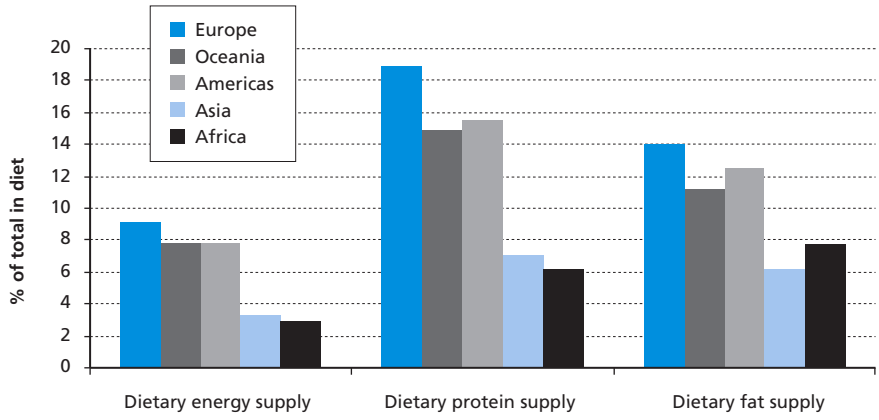
3.2 MILK COMPOSITION

3.2.1 The role of milk as a source of macronutrients

Milk is a major source of dietary energy, protein and fat, contributing on average 134 kcal of energy/capita per day, 8 g of protein/capita per day and 7.3 g of fat/capita per day in 2009[11] (FAOSTAT, 2012). However, when different geographic regions are considered, the contribution from milk to the various nutritional components varies considerably (Figure 3.1): milk provides only 3 percent of dietary energy supply in Asia and Africa compared with 8–9 percent in Europe and Oceania; 6–7 percent of dietary protein supply in Asia and Africa compared with 19 percent in Europe; and 6–8 percent of dietary fat supply in Asia and Africa, compared with 11–14 percent in Europe, Oceania and Americas.

Water is the main component in all milks, ranging from an average of 68 percent in reindeer milk to 91 percent in donkey milk. The main carbohydrate is lactose, which is involved in the intestinal absorption of calcium, magnesium and phosphorus, and the utilization of vitamin D (Campbell and Marshall, 1975, cited in Park *et al*., 2007). Lactose also provides a ready source of energy for the neonate,

FIGURE 3.1
Milk as a source of dietary energy, protein and fat in Europe, Oceania, the Americas, Asia and Africa, 2009



Source: Calculated from data for milk (excluding butter), 2009, from FAOSTAT (http://faostat.fao.org) Europe includes northern, southern, western and eastern Europe; Oceania includes Australia and New Zealand, Melanesia, Micronesia and Polynesia; Americas include northern, South and Central America and the Caribbean; Africa includes eastern, middle, northern, southern and western Africa; Asia includes central, eastern, southern, southeastern and western Asia.

[11] "Milk–excluding butter". The most recent food supply data currently available on FAOSTAT are for 2009.

providing 30 percent of the energy in bovine milk, nearly 40 percent in human milk and 53–66 percent in equine milks (Fox, 2008).

3.2.2 Composition of milks consumed by humans

The proximate compositions of cow, buffalo, goat and sheep milks are given in Table 3.1, while the mineral and vitamin contents of these milks are presented in Table 3.2. Values for human milk have been included in these tables for comparison. Tables 3.3, 3.4 and 3.5 show the proximate composition and mineral and vitamin contents of milk from minor dairy animals. The differences in protein, fat and lactose contents between milks from different species are illustrated in Figure 3.2.

FIGURE 3.2
Protein, fat and lactose contents of milks from different species

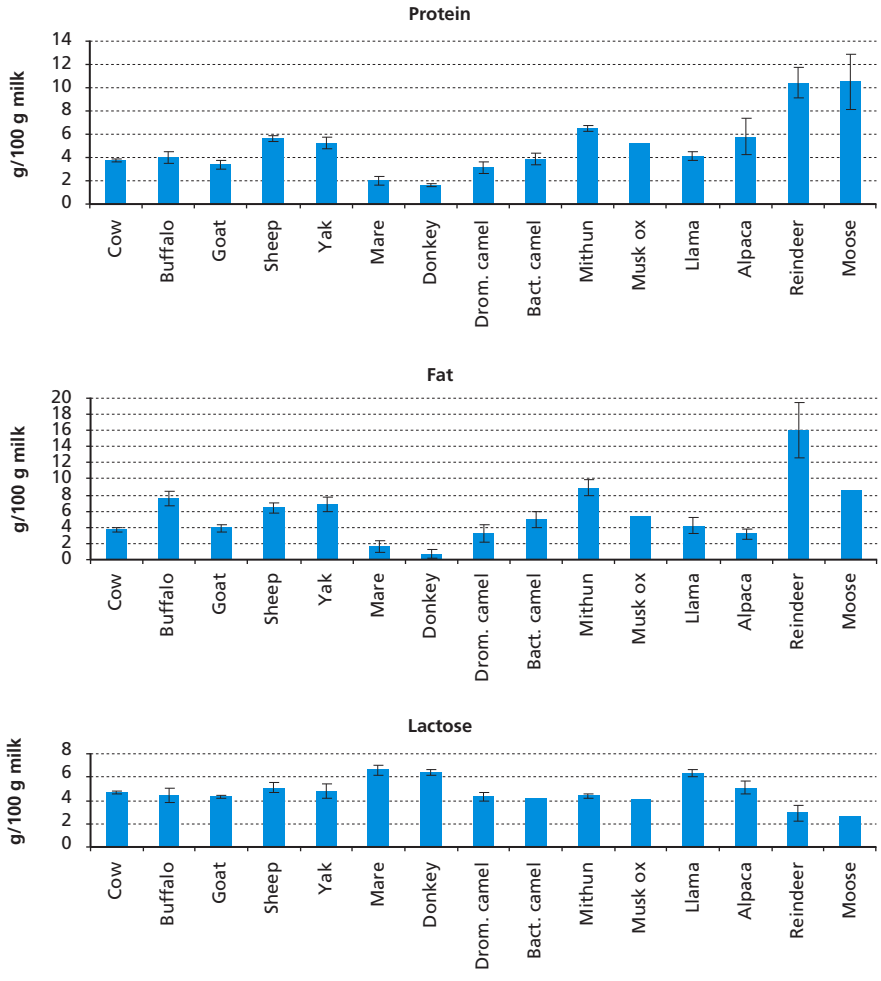


TABLE 3.1
Proximate composition of human, cow, buffalo, goat and sheep milks (per 100 g of milk)*

Proximates	Human	Cow		Buffalo		Goat		Sheep	
	Average	Average	Range	Average	Range	Average	Range	Average	Range
Energy (kJ)	291	262	247–274	412	296–495	270	243–289	420	388–451
Energy (kcal)	70	62	59–66	99	71–118	66	58–74	100	93–108
Water (g)	87.5	87.8	87.3–88.1	83.2	82.3–84.0	87.7	86.4–89.0	82.1	80.7–83.0
Total protein (g)	1.0	3.3	3.2–3.4	4.0	2.7–4.6	3.4	2.9–3.8	5.6	5.4–6.0
Total fat (g)	4.4	3.3	3.1–3.3	7.5	5.3–9.0	3.9	3.3–4.5	6.4	5.8–7.0
Lactose (g)	6.9	4.7	4.5–5.1	4.4	3.2–4.9	4.4	4.2–4.5	5.1	4.5–5.4
Ash	0.2	0.7	0.7–0.7	0.8	0.7–0.8	0.8	0.8–0.8	0.9	0.9–1.0

* Values for human milk (mature, fluid) are from USDA (USDA, 2009), food code 01107. The values for cow, goat and sheep milks were calculated using values where available in the following food composition tables: USDA: cow – food code 01211 "Milk, whole, 3.25 percent milk fat, without added vitamin A and vitamin D"; goat – 01106 "Milk, goat, fluid, with added vitamin D"; sheep – food code 01109 "Milk, sheep, fluid" (USDA, 2009); FSA (2002): cow – food code 12-316 "Whole milk, pasteurized, average (average of summer and winter milk)"; goat – 12-328 "Goats milk, pasteurized"; sheep – food code 12-329 "Sheeps milk, raw" (FSA, 2002); Danish Food Composition Databank: cow – food code 0156 "Milk, whole, conventional (not organic), 3.5 percent fat"; goat – 0516 "Goat milk" (NFI, 2009); New Zealand food composition tables: cow – food code F1028 "Whole milk, pasteurized, average (average of summer and winter milk)"; goat – 12-328 "Goats milk, pasteurized"; sheep – food code F52 "Sheeps' milk, raw" (Esperance *et al.*, 2009); Columbian food composition table: cow – food code G101 "Milk, whole, crude (leche, entera, cruda)"; goat – G086 "goat milk, whole, crude (leche de cabra, entera cruda)" (FAO/LATINFOODS, 2009); Argentinian food composition table: sheep – food code G087 "milk, of sheep, whole, fresh (leche, de oveja, entera, fresca)" (FAO/LATINFOODS, 2009). The number of data points varied.
Values for buffalo milk were obtained from Medhammar *et al.*, 2011.

TABLE 3.2

Vitamin and mineral composition of human, cow, buffalo, goat and sheep milks (per 100 g of milk)*

	Human	Cow		Buffalo		Goat		Sheep		Daily RNI[1] for children, 1–3 yr
	Average	Average	Range	Average	Range	Average	Range	Average	Range	
Minerals										
Calcium (mg)	32	112	91–120	191	147–220	118	100–134	190	170–207	500 mg
Iron (mg)	Tr	0.1	Tr–0.2	0.2		0.3	Tr–0.6	0.1	Tr–0.1	5 mg (12% bioavailability)
Magnesium (mg)	3	11	10–11	12	2–16	14	13–14	18		60 mg
Phosphorus (mg)	14	91	84–95	185	102–293	100.4	90–111	144	123–158	
Potassium (mg)	51	145	132–155	112		202	170–228	148	120–187	
Sodium (mg)	17	42	38–45	47		44	32–50	39	30–44	
Zinc (mg)	0.2	0.4	0.3–0.4	0.5		0.3	0.1–0.5	0.6	0.5–0.7	4.1 mg (Moderate bioavailability)
Copper (mg)	0.1	Tr	Tr–Tr			Tr	Tr–0.1	0.1	0.1–0.1	
Selenium (µg)	1.8	1.8	1.0–3.7			1.1	0.7–1.4	1.7		17 µg
Manganese (µg)		8	4–10			18	Tr–18	18	Tr–18	
Vitamins										
Retinol (µg)	60	35	29–45	69		45	35–56	64	44–83	
Carotene (µg)	7	16	7–23			13	Tr–18[2]	Tr		
Vitamin A (µg RE)	61	37	30–46	69		48	30–74	64		Mean requirement: 400 µg RE
Vitamin E (mg)	0.08	0.08	0.07–0.08	0.19	0.19–2.0	0.05	0.03–0.07	0.11	0.11–0.11	
Thiamin (mg)	0.01	0.04	0.02–0.04	0.05		0.06	0.03–0.09	0.07	0.07–0.08	0.5 mg

TABLE 3.2 *(continued)*

	Human	Cow		Buffalo		Goat		Sheep		Daily RNI[1] for children, 1–3 yr
	Average	Average	Range	Average	Range	Average	Range	Average	Range	
Vitamins										
Riboflavin (mg) (vit B_2)	0.04	0.20	0.17–0.20	0.11		0.13	0.04–0.18	0.34	0.32–0.36	0.5 mg
Niacin (mg)	0.18	0.13	0.09–0.20	0.17		0.24	0.10–0.30	0.41	0.40–0.42	6* mg
Niacin equivalent (mg)		0.79	0.70–0.80			1.00	1.00–1.00			
Pantothenic acid (mg)	0.22	0.43	0.34–0.58	0.15		0.30	0.31–0.41	0.43	0.41–0.45	2.0 mg
Vitamin B_6 (mg)		0.04	0.03–0.06	0.33		0.05	0.05–0.06	0.07	0.06–0.08	0.5 mg
Folate (µg)	5.0	8.5	5.0–8.0	0.6		1.0	Tr–1.0	6.0	5.0–7.0	150 µg
Biotin (µg)		2.0	1.4–2.5	13.0		2.5	2.0–3.0	2.5	2.5–2.5	8.0 µg
Vitamin B_{12} (µg)	0.05	0.51	0.25–0.90	0.40		0.07	0.04–0.10	0.66	0.60–0.71	0.9 µg
Vitamin C (mg)	5.0	1.0	0.0–2.0	2.5		1.1	1.0–1.3	4.6	4.2–5.0	30 mg
Vitamin D (µg)	0.1	0.2	0.1–0.3			0.1	0.1–0.1	0.2	0.2–0.2	5 µg

* The number of data points varied. Blank spaces indicate that no data were available. See Table 3.1 footnote for data sources.
[1] Recommended nutrient intake values from FAO and WHO, 2002.
[2] Although some papers, e.g. Park *et al.* (2007), say that goats convert all β-carotene to vitamin A, resulting in caprine milk being whiter than bovine milk, some of the above databases reported values for β-carotene in goat milk.
RE: retinol equivalents in µg = µg retinol + 1/6 µg β-carotene + 1/12 µg other provitamin A carotenoids; Tr: traces.

TABLE 3.3

Proximate composition of milk from minor dairy animals (average and range, per 100 g of milk)

		Yak	Mare	Donkey	Dromedary camel	Bactrian camel	Mithun	Musk ox	Llama	Alpaca	Reindeer	Moose
Energy, calculated* value, kJ (kcal)	Average	417 (100)	199 (48)	156 (37)	234 (56)	319 (76)	510 (122)	356 (85)	326 (78)	299 (71)	819 (196)	538 (129)
	Range	335–557 (80–133)	171–295 (41–71)	135–215 (32–51)	185–332 (44–79)		458–575 (110–138)		258–358 (62–86)	237–351 (57–84)	525–1079 (126–258)	
Energy, reported value, kJ (kcal)	Average	368 (89)	193 (46)	210 (50)					392 (94)		880 (209)	
	Range	349–382 (87–91)	177–210 (42–50)						388–396 (93–95)		680–1139 (162–272)	
Water (g)	Average	82.6[a]	89.8[b]	90.8[b]	89.0[b]	84.8	78.6	83.6	84.8	83.7	67.9[c]	76.8
	Range	75.3–84.4	87.9–91.3	89.2–91.5	88.7–89.4		77.4–79.7		83.7–86.9	83.2–84.2	61.9–76.3	74.3–79.2
Total protein (g)	Average	5.2[b]	2.0[c]	1.6[c]	3.1[d]	3.9	6.5	5.3	4.1	5.8	10.4[e]	10.5
	Range	4.2–5.9	1.4–3.2	1.4–1.8	2.4–4.2	3.6–4.3	6.1–6.8		3.4–4.3	3.9–6.9	7.5–13.0	7.8–14.4
Total fat (g)	Average	6.8[a]	1.6[b,e]	0.7[b]	3.2[e]	5.0	8.9	5.4	4.2	3.2	16.1[c]	8.6
	Range	5.6–9.5	0.5–4.2	0.3–1.8	2.0–6.0	4.3–5.7	7.7–10.3		2.7–4.7	2.6–3.8	10.2–21.5	7.0–10.0
Lactose (g)	Average	4.8[a]	6.6[b]	6.4[b]	4.3[a]	4.2	4.4	4.1	6.3	5.1	2.9[c]	2.6
	Range	3.3–6.2	5.6–7.2	5.9–6.9	3.5–4.9		4.1–4.6		5.9–6.5	4.4–5.6	1.2–3.7	0.6–3.6
Ash (g)	Average	0.8[a]	0.4[b]	0.4[b]	0.8[a]	0.9	0.9	1.6	0.7	1.6	1.5[c]	1.6
	Range	0.4–1.0	0.3–0.5	0.3–0.4					0.6–0.9	1.4–1.7	1.2–2.7	1.5–1.6

* Values were obtained from Medhammar *et al.*, 2011. Blank spaces indicate that no data were available.

The table includes the results of the statistical analysis for buffalo, yak, mare, donkey, dromedary camel and reindeer milks; the other milks did not have enough data points to include them in this analysis. Values in a row with different superscripts are significantly different ($P < 0.05$).

TABLE 3.4
Mineral composition in milk from minor dairy animals (per 100 g of milk)

		Yak	Mare	Donkey	Dromedary Camel	Bactrian Camel	Mithun	Llama	Reindeer	Moose	Daily RNI* for children, 1–3 yr
Calcium (mg)	Average	129	95	91	114	153.7	88	195	320	280	500 mg
	Range	119 –134	76–124	68–115	105–120	152.3–155		170–220		156–358	
Iron (mg)	Average	0.6	0.1		0.2					0.3	5 mg (12% bioavailability)
	Range	0.2–1.0	Tr–0.2		0.2–0.3						
Magnesium (mg)	Average	10	7	4	13	8		15	19	23	60 mg
	Range	8–12	4–12		12–14					19–26	
Phosphorus (mg)	Average	106	58	61	86	132	147	122	270	276	
	Range	77–135	43–83	49 –73	83–90	117–146					
Potassium (mg)	Average	95	51	50	151	186		120	156	111	
	Range	83–107	25–87		124–173	181–191				82–150	
Sodium (mg)	Average	29	16	22	66	66		27	48	78	
	Range	21–38	13–20		59–73	61–72			46 –50	37–158	
Zinc (mg)	Average	0.9	0.2		0.6	0.7			1.1	0.6	4.1 mg (Moderate bioavailability)
	Range	0.7–1.1	0.2–0.3		0.4–0.6						
Copper (mg)	Average	0.4	0.1		0.2					0.3	
	Range		Tr–0.1		0.1–0.2						
Selenium (µg)	Average									11	17 µg
Manganese (µg)	Average				106					1	
	Range				60–180						

Values were obtained from Medhammar *et al.*, 2011. Blank spaces indicate that no data were available.
* Recommended nutrient intake values from FAO and WHO, 2002.
Tr:traces.

TABLE 3.5
Vitamin content in milk from minor dairy animals (per 100 g of milk)

		Mare	Donkey	Dromedary camel	Bactrian camel	Daily RNI* for children, 1–3 yr)
Vitamin A (µg) RE	Average				97	Mean requirement: 400 µg RE
Vitamin E (mg) (alpha-tocopherol)	Average				0.15	
Thiamin (mg)	Average	0.03	0.06		0.01	0.5 mg
	Range	0.02–0.04				
Riboflavin (mg)	Average	0.02	0.03	0.06	0.12	0.5 mg
	Range	0.01–0.03				
Niacin (mg)	Average	0.07	0.09			6* mg
Pantothenic acid (mg)	Average					2.0 mg
Vitamin B_6 (mg)	Average				0.05	0.5 mg
Folate (µg)	Average					150 µg
Biotin (µg)	Average					8.0 µg
Vitamin B_{12} (µg)	Average					0.9 µg
Vitamin C (mg)	Average	4.3		3.8	3.0	30 mg
	Range	1.7–8.1		2.5–18.4		
Vitamin D (µg)	Average				1.6	5 µg

Values were obtained from Medhammar *et al.*, 2011. Blank spaces indicate that no data were available.
* Recommended Nutrient Intake values from "Human vitamin and mineral requirements" (FAO and WHO, 2002).
RE: retinol equivalents in µg = µg retinol + 1/6 µg β-carotene + 1/12 µg other provitamin A carotenoids.

Cow milk

Traditionally, two cattle species have been recognized, *Bos taurus* (humpless cattle) and *Bos indicus* (zebu cattle), although there is no reproductive barrier between them. Some listings identify as many as 1 000 cattle breeds, even though some of these are actually local varieties of a breed (Buchanan, 2002). Even so, nearly 35 percent of dairy cows (about 70 million head) belong to the Holstein-Friesian breed. The popularity of this breed is largely because of its high average milk production (Fox, 2008) and superior ability to convert feed into protein (Buchanan, 2002). This is not an ideal situation from a biodiversity point of view, and widespread use of this one breed may put some breeds in danger of extinction (Buchanan, 2002).

Cow milk accounted for 83 percent of global milk production in 2010 (FAOSTAT, 2012). Cow milk contains more protein and minerals, especially

calcium and phosphorus, than human milk (Table 3.1). This is because a young calf grows faster than a child and hence has higher nutritive demands: on average, a calf takes only 10 weeks to double its birth weight, compared with 20 weeks for a human baby (Walker, 1990). The protein in cow milk is of high-quality (defined as protein that supports maximal growth), containing a good balance of all the essential amino acids, including lysine. Many human diets are deficient in certain essential amino acids. For example, wheat and maize-based diets contain only 57 percent and 58 percent of required levels of lysine, and cassava-based diets are deficient in leucine, valine and isoleucine, containing only 79 percent of required levels (WHO, FAO and UNU, 2007). More than 600 million people depend on cassava in Africa, Asia and Latin America for food security (FAO, 2002). Including milk (and dairy products) in staple-based diets increases availability of these limiting amino acids, improving overall dietary quality.

Cow milk contains more protein than does human milk, but human milk contains more lactose, resulting in comparable energy contents. Cow milk and human milk differ in the amounts of various proteins they contain. Human milk does not contain β-lactoglobulin, one of the main proteins associated with cow milk allergy.[12] Caseins comprise nearly 80 percent of the protein in cow milk but less than 40 percent in human milk. Caseins can form leathery curds in the stomach and be difficult to digest. In addition, the type of caseins that predominate in the two milks also differs, human milk containing more β-casein, which is more susceptible to peptic hydrolysis than α_S-casein, particularly α_{s1}-casein, which predominates in cow milk (El-Agamy, 2007). The casein content of cow milk varies between breeds and cheese makers often use milk from breeds with a higher κ-casein content in their milk (Bonfatti *et al.*, 2010).

Cow milk generally contains between 3 and 4 g of fat/100 g, although values as high as 5.5 g/100 g have been reported in raw milk. Most milks consumed now contain a standardized fat content of around 3.5 g/100 g. Cow milk contains a higher proportion of saturated FA (SFA) than does human milk: 65–75 g/100 g total FAs, of which about 40 percent are C12:0–C16:0. Cow milk also has a high content of C18:0. The monounsaturated FA (MUFA) that is present in highest concentration in cow milk is C18:1 (oleic acid).

The conjugated linoleic acid (CLA) content in cow milk is generally reported to vary from 0.1 to 2.2 g/100 g total FA depending on season, region, farming system and feeding, and animal and breed (Elgersma, Tamminga and Ellen, 2006). For example, milk from the Mafriwal cow breed was shown to contain a significantly higher ($P < 0.05$) percentage of CLA than Jersey cow milk (0.35 g/100 g total FA vs 0.23 g/100g total FA) (Yassir *et al.*, 2010). This has possible implications with regard to promoting cow breeds with a higher CLA content in their milk.

Levels of water-soluble vitamins in human milk reflect maternal levels and depend on the mother's diet, but these vitamins are synthesized within the body of the cow and levels are not diet-dependent in cow milk.

[12] Allergy to cow milk is covered in Chapter 4.

Buffalo milk

Water buffalo (*Bubalus bubalis*) milk is ranked second in the world in production, contributing 11.1 percent of the world milk production in 2006–09, with India (60 percent) and Pakistan (30 percent) being the main producers (FAOSTAT, 2012). Buffalo have historically been divided into swamp and river buffalo based on morphological, behavioural and geographical criteria (Groeneveld *et al.*, 2010). They are sometimes referred to as different subspecies; river buffalo as *Bubalus bubalis bubalis* and swamp buffalo as *Bubalus bubalis carabenesis*. Swamp buffalo are reported to be mainly used as draught animals (Talpur, Memon and Bhanger, 2007) and their milk yield is poor (Meena, Ram and Rasool, 2007). River buffalo are used mainly for milk production (Han *et al.*, 2007).

Buffalo milk contains more than twice as much fat as cow milk on average (7.5 g/100 g vs 3.3 g/100 g; Table 3.1) and is therefore more energy dense. The high fat content makes it particularly suitable for processing, with the production of 1 kg of butter requiring 14 kg of cow milk compared with only 10 kg of buffalo milk (Ménard *et al.*, 2010). The proportion of SFA in buffalo milk, 65–75 g/100 g total FA, is comparable to that in cow milk.

Goat milk

Milk from goats (*Capra hircus*) accounted for 2.4 percent of global milk production in 2010 (FAOSTAT, 2012). India is the main producer of goat milk (30 percent), followed by Bangladesh (17 percent) and Sudan (11 percent). Home consumption of goat milk is reported to be very high: goats are the main suppliers of dairy and meat products for rural populations (Haenlein, 2004). Some goat breeds, such as the Bedouin goat, are able to survive under extreme environmental conditions on meagre fodder and water intake, which makes them particularly suited for surviving in regions with harsh climatic conditions. However, the goat is not just associated with underdevelopment and poverty – dairy goat farming is also significant to the economies of some Mediterranean countries (Boyazoglu, Hatziminaoglou and Morand-Fehr, 2005) owing to the connoisseur interest in goat milk products such as cheeses and yoghurt (Haenlein, 2004).

The proximate composition of goat milk is very similar to that of cow milk (Table 3.1). In contrast to cow milk, the lactose content of goat milk can be increased by supplementing the diet with plant oil (Chilliard *et al.*, 2005, cited in Raynal-Ljutovac *et al.*, 2008).

The proportion of SFA in goat milk (65–75 g/100 g total FA) is comparable to that in cow milk. However, goat milk is rich in short- and medium-chain FAs with 6–10 carbon atoms, containing up to twice as much as cow milk (Sanz Sampelayo *et al.*, 2007). For this reason, caproic (C6:0), caprylic (C8:0) and capric acids (C10:0) are named after goats. These FAs have a different metabolism to that of long-chain FAs and are a source of rapidly available energy, particularly relevant for people suffering from malnutrition or fat absorption syndrome and in the diets of pre-term babies (feeding formulas for premature infants often contain medium-chain triacylglycerols) and elderly people (Raynal-Ljutovac *et al.*, 2008). Goat milk also contains branched-chain FAs with fewer than 11 carbon atoms, of which there are almost none in cow milk; this is thought to give goat milk its characteristic "goaty and muttony flavours" (Sanz Sampelayo *et al.*, 2007). Although some reports sug-

gest that goat milk contains less *trans*-C18:1 FA than cow milk, other studies have shown that the *trans*-FA content is similar in the two milks. The actual content depends on the feeding system, management regime and diet.

Goat milk has a smaller fat globule size than cow milk which may make it more easily digestible (Raynal-Ljutovac *et al.,* 2008). Anecdotal evidence, stemming in part from cultural beliefs and in part from research studies (see references cited in Haenlein, 2004; Ribeiro and Ribeiro, 2010), suggests that goat milk has lower allergenicity than cow milk. These studies report that although goat milk contains the same proteins (including β-lactoglobulin) as cow milk, some goat milk proteins differ in their genetic polymorphisms, resulting in lower allergenicity. The major fraction in goat casein is β-casein, which makes it similar to human milk. Milk from some goat breeds that lack α_{s1}-casein altogether (which predominates in cow milk) has been shown to be less allergenic (El-Agamy, 2007).

However, these reports must be approached with caution. Several studies have shown that goat milk is not appropriate for children with immunoglobulin E (IgE)-mediated cow milk allergy (Bellioni-Businco *et al*., 1999), leading in some cases to allergic reactions including life-threatening anaphylactic shock (Basnet *et al*., 2010). The recent guidelines issued by the World Allergy Organization states that goat milk should not be used as a substitute for children with cow milk allergy (Fiocchi *et al*., 2010).

Goat milk has been reported to contain four times as much of the oligosaccharide sialic acid as cow milk (about 23 mg/100 g vs 6 mg/100 g) (Puente *et al*., 1996, cited in Raynal-Ljutovac *et al*., 2008). Oligosaccharides represent an important fraction of human milk (1.3 g/100 g), and are thought to promote bifidobacteria growth and play a role in brain development in the newborn child.

Goat milk has a higher content of retinol than cow milk. Vitamin B_{12} content in goat milk is an order of magnitude lower than in cow milk. Like cow milk, goat milk is a poor source of folate (Pandya and Ghodke, 2007).

Goat milk contains a relatively large amount of free amino acids, particularly of the non-protein amino acid taurine (obtained biosynthetically from cysteine) at 9 mg/100 g (Grandpierre *et al*., 1988 cited in Raynal-Ljutovac *et al*., 2008). This is 20-fold more than in cow milk and is similar to the level in human milk. A higher content of cysteine (53 percent more than in cow milk) is also reported in goat milk.

Sheep milk

Although China was the top producer of sheep (*Ovis aries*) milk in 2010 (17 percent), about 61 percent of the world's sheep milk is produced in the Mediterranean region and Middle East, and mainly used as a raw material for producing cheese and other dairy products.

Much less information is available on sheep milk composition than on cow, buffalo and goat milks. Although some reviews cover both goat and sheep milks (Jandal, 1996; Pandya and Ghodke, 2007; Park *et al*., 2007; Raynal-Ljutovac *et al*., 2008), most discuss goat milk in depth and sheep milk only superficially. Most studies are related to effects of animal feeding on FA composition (Goulas, Zervas and Papadopoulos, 2003; Castro *et al*., 2009; Talpur, Bhanger and Memon, 2009).

The average contents of protein (5.6 g/100 g) and fat (6.4 g/100 g) in sheep milk is high; only buffalo milk contains more fat on average (Table 3.1) when milk

from major dairy species is considered. Sheep milk also contains more lactose than human, cow, buffalo and goat milks. The higher lactose content is compensated for by lower sodium and potassium levels, although most of the other minerals are present in higher amounts in sheep milk, in line with the higher ash content.

The FA profile of sheep milk is fairly similar to that of goat milk: five FAs make up more than 75 percent of the fat (C10:0, C14:0, C16:0, C18:0 and C18:1). SFA content (65–75 g/100 g total FA) is comparable to that in cow, buffalo and goat milks. The average fat globule size is reported to be even smaller in sheep milk than in goat milk.

Sheep milk contains more retinol than cow and goat milks. As in goat milk, the non-protein amino acid taurine is reported to be present in sheep milk (Park *et al*., 2007).

Yak milk

The yak *(Bos grunniens*) is the only bovine reared in the mountainous regions of China, Mongolia, Russia, Nepal, India, Bhutan, Tajikistan and Uzbekistan, and hence the populations rely on the yak for milk, meat, fur and transportation (Wiener, 2002 cited in Silk *et al*., 2006). Several factories in China, Nepal and Mongolia produce dried yak milk for domestic consumption (Park and Haenlein, 2006).

The proximate composition of yak milk is very similar to that of buffalo milk: the milks are significantly different ($P < 0.05$) only in their total protein content. Like buffalo milk, the fat content of yak milk is much higher than of cow milk, while its water content is more than 5 g/100 g lower. An analysis of published studies on yak milk showed that the water content can vary by as much as 10 g/100 g among samples of yak milk.

The predominant FAs in yak milk are the same as in cow and buffalo milks, and similarly, only a small amount of polyunsaturated FA (PUFA) is reported (2 g/100 g total FA). SFA accounts for about 65 g/100 g total FA in yak milk. The short chain C4:0–C10:0 content is low in yak milk. Small quantities (0.2 g/100 g total FA) of CLA have also been reported.

Yak milk contains almost twice as much β-lactoglobulin (average 708 mg/100 g) as in cow milk (300–400 mg/100 g). Yak milk was also reported to contain 67 mg of lactoferrin/100 g, 2–6 times more than values reported in cow milk (Król *et al*., 2010; Lefier *et al*., 2010).

Mare and donkey milks

Mare (*Equus caballus*) and donkey (*Equus asinus*) milks are renowned for their therapeutic properties (Mittaine, 1962; Doreau and Martin-Rosset, 2002; Malacarne *et al*., 2002). Approximately 30 million people in Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Mongolia and eastern and central Europe drink mare milk (Doreau and Martin-Rosset, 2002). These two monogastric species produce similar milk, with no significant differences between them ($P < 0.05$) in protein, fat, lactose, ash or water contents (Table 3.3). Their milks contain substantially lesser amounts of fat and protein than cow milk, and are nearest in composition to human milk because of their high lactose and low protein contents (FAO, 1972). Their ash contents are also lower than that of cow milk (0.3–0.5 g/100 g vs 0.7 g/100 g) and thus more similar to human milk (0.2 g/100 g). According to some reports, mare milk

can contain up to 15 mg of ascorbic acid/100 g, much more than cow milk (Marconi and Panfili, 1998).

Compared with cow milk, equine milk fat has a high content of PUFA (more than 20 g/100 g total FA in both mare and donkey milks compared with about 6 g/100 g total FA in cow milk) and a low content of SFA (average 40 g/100 g total FA in mare milk and 55 g/100 g total FA in donkey milk, compared with 65–75 g/100 g total FA in cow milk). The milks also contain the indispensable FAs alpha-linolenic acid (ALA) and linoleic acid (LA) (6 g ALA/100 g total FA in mare milk and 4 g ALA/100 g total FA in donkey milk; 10 g LA/100 g total FA in mare milk, 6 g LA/100 g total FA in donkey milk). Values for ALA in cow, goat and sheep milks range between 2 and 4 g/100 g total FA, and values for LA between 0.3 and 0.6 g/100 g total FA (Rodríguez-Alcalá, Harte and Fontecha, 2009). In human milk ALA can range from 1 to 3 g/100 g (Malacarne *et al*., 2002). The high LA and ALA contents and low C18:0 content of equine milks are attributed to equines being monogastric animals: FAs are hydrogenated in the digestive tract of ruminants before absorption, but not in the digestive tract of equines (Jenkins *et al*., 1996, cited in Chiofalo, Salimei and Chiofalo, 2001). The unsaturated long chain FA content of equine milk is related to amounts consumed with forage (Chiofalo, Salimei and Chiofalo, 2001; Pelizzola *et al*., 2006). No *trans*-FA or CLA have been reported in donkey milk, while mare milk has been reported to contain negligible amounts of CLA and *trans*-C18:1 (vaccenic acid) (Jahreis *et al*., 1999).

The equine milks resemble human milk in their relatively low content of caseins (40–45 percent of total protein content). A recent study showed that caseins in equine milks are rapidly digested by gastric juices, in contrast to the caseins from cow and goat milks which are digested slowly (Inglingstad *et al*., 2010). As 40–50 percent of equine milk protein consists of whey protein, equine milk is not very suitable for cheese production. The whey proteins include lysozyme, which has been reported at 100–200 mg/100 g of donkey milk, compared with only 7–13 µg/100 g of cow milk (Uniacke-Lowe, Huppertz and Fox, 2010). Although equine milk whey contains β-lactoglobulin, the sequence homology between proteins isolated from equine milks and cow milk is only 60 percent. Owing to the similarity of milk proteins in equine and human milk, equine milks have been recommended for children with severe IgE-mediated cow milk protein allergy (Businco *et al*., 2000).

To summarize, the similarity of equine milk to human milk in total protein and lactose contents and FA and protein profiles and the fairly low mineral content suggests that equine milk could be a better food for infants than is cow milk (Iacono *et al*., 1992; Malacarne *et al*., 2002), although the lower total fat in equine milks make them less energy dense than human milk. Although one study documents the use of donkey milk to feed unweaned infants (Ziegler, 2007), further studies are needed, particularly because adverse effects on iron nutrition may be expected. The protein profile of equine milk makes it particularly suitable for consumption by people who are allergic to cow milk.

Dromedary camel and Bactrian camel milks

In arid and semi-arid areas camels play a major role in supplying the population with milk (FAO, 1982). There are two species of camel, the dromedary or Arabian camel (*Camelus dromedaries,* single-humped) mainly found in desert areas

in the Middle East, North and East Africa, Southwest Asia and Australia, and the Bactrian camel (*Camelus bactrianus*, two-humped), found in northwestern China and Mongolia, southern Russia, Tajikistan and Kazakhstan. Out of an estimated 18 million camels in the world only 2 million are Bactrian camels (Alhadrami, 2003). Sub-Saharan Africa accounted for over 87 percent of camel milk production in 2006-9 (FAOSTAT, 2012). Somalia is the largest single producer of camel milk (53 percent of global camel milk production), followed by Ethiopia (12 percent) and Mali (8 percent) (FAOSTAT, 2008). Camelids have a stomach with three compartments rather than four but with similar functional properties to ruminant stomachs (Schoos *et al*., 2008); therefore they are sometimes called "pseudo-ruminants".

The lactose and protein contents in the milk from the two camel species are similar but their fat contents are different, with Bactrian camel milk containing more fat. In overall proximate composition, dromedary camel milk is very similar to cow milk.

The SFA content of Bactrian camel milk (average 50 g/100 g total FA) appears to be lower than that of cow milk, while that of dromedary camel milk (average 60 g/100 g total FA) may be slightly lower than that of cow milk. The main FAs reported in most studies of dromedary camel milk are C16:0, C14:0, C18:0, C18:1 and C16:1, although a few studies found high contents of C9:0 and C10:1 (Gorban and Izzeldin, 1999), which are unusual for milk. The MUFA content in dromedary camel milk (56–80 g/100 g total FAs) is higher than in cow milk (26 g/100 g total FAs) (Medhammar *et al.* 2011). The content of very short chain FAs (C4–C8) is low compared with most milks including cow milk. It has been suggested these FAs, which are produced by cellulose fermentation in the rumen, may be rapidly metabolized by camel tissue and are therefore not excreted in the milk (Gorban and Izzeldin, 2001). Although some authors have commented on the high PUFA content of camel milk compared with cow milk (Gorban and Izzeldin, 2001; Alhadrami, 2003; Zhang *et al*., 2005; Jirimutu *et al*., 2010) and suggested that biohydrogenation of polyunsaturated FA may be less extensive in the rumen of camel than in cow (Gorban and Izzeldin, 2001), C18:1 was erroneously included with PUFA in some of these papers (Zhang *et al*., 2005; Jirimutu *et al*., 2010). Milk from both camel species contains 1–2 g of ALA and LA/100 g total FA.

Dromedary camel and Bactrian camel milks do not contain measurable amounts of β-lactoglobulin and are similar to human milk in this respect (Fernandez and Oliver, 1988; Merin *et al*., 2001; Jirimutu *et al*., 2010). Therefore, the main whey protein is α-lactalbumin, unlike in cow milk whey in which this protein makes up only 25 percent of the total whey protein (Al Haj and Al Kanhal, 2010). As in human milk, β-casein is the main camel milk casein (Al Haj and Al Kanhal, 2010). These two characteristics could contribute to dromedary camel milk having a higher digestibility rate and lower incidence of allergy than cow milk (El-Agamy *et al*., 2009). However, these differences in protein composition are reported to lead to difficulties in cheese manufacture with camel milk (Al Haj and Al Kanhal, 2010).

Perhaps more than any other milk, camel milk has had various therapeutic benefits attributed to it (see Al Haj and Al Kanhal, 2010). In fact, both dromedary and Bactrian camel milks contain greater quantities of bioactive substances and antimicrobial components such as lysozyme, lactoferrins and immunoglobulins than do cow and buffalo milks. The high lysozyme content in camel milk delays growth of yoghurt culture, causing problems in yoghurt production (Abu-Taraboush, 1996

and Jumah *et al.*, 2001, cited in Al Haj and Al Kanhal, 2010). Even though the antimicrobial components in camel milk are more heat stable than those in cow and buffalo milk, heating camel milk to 100 °C for 30 minutes results in a total loss of antimicrobial activity (El-Agamy, 2007).

The vitamin C content of dromedary camel milk shows a wide range, depending on breed, ranging from 2.5 mg/100 g in the Majaheem breed from Saudi Arabia (Mehaia, 1994) to 18.4 mg/100 g milk in the Arvana breed from Kazakhstan (Konuspayeva *et al.*, 2010). However, vitamin C in camel milk may be more heat-sensitive than in cow milk, decreasing by about 27 percent when the milk is pasteurized (Mehaia, 1994).

Mithun milk

The domesticated bovine species, mithun (*Bos frontalis*), is mainly found in the hill regions of India, Myanmar, Bhutan and Bangladesh (Nath and Verma, 2000), where it plays an important role in the economic, social and cultural life of the local people. Hybrids of mithun and cattle are used as dairy animals in parts of northeastern India and Bhutan (NRCM, 2010).

Very few studies are available on the composition of mithun milk. The milk contains more total fat (8.9 g/100 g) and total protein (6.5 g/100 g) than cow milk (3.3 g fat and 3.3 g protein/100 g milk) (Mech *et al.*, 2008). The high fat and protein contents in mithun milk are attributed to the unique genetic makeup of this species and to its low milk yield (Mondal *et al.*, 2001; Mech *et al.*, 2008).

Musk ox milk

The musk ox (*Ovibos moschatus*) is an Arctic mammal that belongs to the subfamily Caprinae, as do goat and sheep. Data on only proximate composition were available for musk ox, obtained from one study (Tener, 1956 cited in Alston-Mills, 1995). Musk ox milk contains more protein and fat but less lactose and water than cow milk. However, the fat content (5.4 milk g/100 g) is not high for an Arctic animal. The ash content in musk ox milk is more than double that of cow milk (1.6 g/100 g compared with 0.7 g/100 g).

Llama and alpaca milks

Llama (*Lama glama*) and alpaca (*Lama pacos*), both domesticated species of South American camelids, have historically not been bred for dairy purposes. Information on milk composition and consumption is scarce. These milks are an underutilized nutritional and economic resource for the people living in the mountainous areas of South America (Fernandez and Oliver, 1988; Riek and Gerken, 2006).

Alpaca milk is richer in protein and ash than milks from the other camelids and cow milk. Llama milk does not contain measurable amounts of β-lactoglobulin (Fernandez and Oliver, 1988; Merin *et al.*, 2001; Jirimutu *et al.*, 2010).

No studies are available on the FA composition of alpaca milk, but one study (Schoos *et al.*, 2008) reported the FA composition of llama milk. The proportions of SFA, C4–C10, MUFA and PUFA in llama milk fat are comparable to the values in cow milk. The predominant FAs in llama milk are C16:0, C18:1, C14:0 and C18:0. The milk also contains *trans*-FA at 3 g/100 g total FA (mainly C18:1 *trans*-11), and a small amount of CLA (0.4 g/100 g total FA).

Reindeer and moose milks

Reindeer (*Rangifer tarandus*) herding is carried out from northern Scandinavia to eastern Siberia. Renewed interest in reindeer milk lies in the expanding market for gourmet products (Holand *et al*., 2002). Moose (*Alces alces*), also known as European elk, are found in the Baltic states, Canada, Finland, Norway, Russia, Sweden and United States (Alaska). Moose milking farms can be found in Russia and Sweden (Minaev, 2010; Dreiucker and Vetter, 2011).

Both these species are noted for their concentrated milks, which have a cream-like consistency and very high fat and protein contents (Cook, Rausch and Baker, 1970; Holand, Gjøstein and Nieminen, 2006). The total fat in reindeer milk can be over six times as high as in cow milk (21.5 g/100 g compared with 3.3 g/100 g), and the protein content four times as high as in cow milk (13.0 g/100 g compared with 3.3 g/100 g). The high protein and fat contents make these milks energy dense. The high energy and protein contents enable the calf to survive the harsh Arctic winter; the concentrated milk is particularly suited to the migratory lifestyle of the reindeer (Gjøstein, Holand and Weladji, 2004). The high protein content also means a higher content of amino acids, all amino acids being present in amounts that are 2–6 times those found in cow milk. Reindeer milk may be suitable as a protein supplement, especially for athletes, given the high absolute content of almost all amino acids in reindeer milk compared with milk from other dairy animals (Holand, Gjøstein and Nieminen, 2006).

About 80 percent of the protein in reindeer milk is caseins, similar to cow milk. Although reindeer milk contains β-lactoglobulin, one study has reported that there is only partial cross-reactivity between cow and reindeer milks, suggesting that reindeer β-lactoglobulin lacks important bovine epitopes that bind IgE (Suutari *et al*., 2006). No information was found on the protein profile of moose milk.

Both reindeer and moose milks are low in lactose, containing nearly half the value found in cow milk (average values of 2.9 and 2.6 g/100 g compared with 4.7 g/100 g), although the lactose content of moose milk can be as low as 0.6 g/100 g milk (Cook, Rausch and Baker, 1970). The Saami people, who are reindeer herders, are reported to be rather intolerant of lactose; hence reindeer milk is particularly suitable as part of their diet (Holand, Gjøstein and Nieminen, 2006). Moose milk could provide an alternative source of dairy for people displaying a reduced tolerance of lactose (see Chapter 4 for discussion of lactose maldigestion/malabsorption).

Both reindeer and moose milks have a high ash content. Mineral values as high as 358 mg of calcium/100 g, 158 mg of sodium/100 g and 150 mg of phosphorus/100 g have been reported in moose milk (Cook, Rausch and Baker, 1970; Franzmann, Flynn and Arneson, 1976; Chalyshev and Badlo, 2002).

The FA profile of reindeer milk is similar to that of cow milk; SFA predominates and the main FAs are C16:0, C18:1, C18:0 and C14:0. Very few studies are available on the FA profile of moose milk. According to these reports, the SFA content (average 53 g/100 g total FA) of the milk is lower than in cow milk (65–75 g/100 g total FA). Moose milk has a high content of PUFA compared with cow milk, with an average of 14 g/100 g total FA (range 8–25 g/100 g total FA) compared with about 6 g/100 g total FA in cow milk. C4–C10 FA contents are unusually low, with an average of 4 g/100 g total FA (range 0–15 g/100 g total FA). The main FAs are C 18:1, C16:0 and C18:0, with a relatively small amount (2–5 g/100 g total FA) of C14:0 when compared with milk from other species (Dreiucker and Vetter, 2011).

Reindeer milk was reported to contain *trans*-FA at 3 g/100 g total FA and LA (C18:2 n-6) at 2 g/100 g total FA, while moose milk contained more LA (average 8 g/100 g total FA) (Medhammar *et al.*, 2011).

3.2.3 Factors affecting milk composition

Milk composition is affected by various factors, including stage of lactation, breed differences, number of calvings (parity), seasonal variations, age and health of animal, feed and management effects including number of milkings per day and herd size (Laben, 1963; Bansal *et al.*, 2003; Walker, Dunshea and Doyle, 2004; Jenkins and McGuire, 2006). This section focuses on the effects of feed and stage of lactation.

Animal feed and milk composition

The influence of animal feed on milk composition has been, and continues to be, the focus of many studies. Milk can be modified to improve it nutrient value and sensory quality by changing the animal's diet (Palmquist, Beaulieu and Barbano, 1993; Mesfin and Getachew, 2007; Castagnetti *et al.*, 2008; Slots *et al.*, 2009; Vera, Aguilar and Lira, 2009; Wiking *et al.*, 2010). For a review on the effects of nutrition and management on the production and composition of milk fat and protein, see Walker, Dunshea and Doyle (2004).

Several studies have looked at methods to increase long-chain n-3 PUFA (such as docosahexaenoic acid [DHA] and eicosapentaenoic acid [EPA]), CLA and C18:1 *trans*-11 (vaccenic acid), all of which have been proposed to have beneficial effects on human health (see Cruz-Hernandez *et al.*, 2007, and references therein for information on the effects of C18:1 *trans*-11). C18:1 *trans*-11 is produced in rumen bacteria from dietary PUFA, and is subsequently converted by Δ^9-desaturase into CLA in the tissues of ruminants (Cruz-Hernandez *et al.*, 2007). Enrichment of milk and meat fats of ruminants with CLA and C18:1 *trans*-11 depends on forage-to-concentrate ratio, the type of forage, the starch source in the concentrate, the plant oil (e.g. sunflower, safflower oil, linseed etc.) added and its PUFA content and composition and inclusion of fish oil, fish meal or algae (see Cruz-Hernandez *et al.*, 2007, and references therein). Plant secondary metabolites such as essential oils, phenolic compounds and saponins have been suggested as a potential means to manipulate bacterial populations involved in ruminal biohydrogenation and thereby modify the FA composition of ruminant-derived food products such as milk (Benchaar and Chouinard, 2009).

Grass-fed cows produce milk with significantly higher CLA contents than cows fed concentrate-based diets, with values as high as 3.3 g/100 g total FA (Jutzeler van Wijlen and Colombani, 2010). Slots *et al.* (2009) reported that an extensive feeding system that incorporated pasture increased the CLA and C18:1 *trans*-11 content in cow milk. The milk fat of cows grazed in the Alps has also been reported to be exceptionally high in CLA, ranging from 1.9–2.9 g/100 g total FA (Kraft *et al.*, 2003), although it has been suggested that this may be linked to grass feeding in general rather than being the result of a specific alpine pasture effect (Leiber *et al.*, 2005). Milk from grass-fed cows (irrespective of whether grazed or barn-fed) contained up to 96 percent more ALA and 134 percent more α-tocopherol (attributed to the high amounts of α-tocopherol in the grass), when compared with milk from cows fed a silage-concentrate diet (Leiber *et al.*, 2005).

Similar effects have been found in dairy goats. Pajor *et al.* (2009) reported significantly higher protein, fat, ALA, PUFA and n-3 FAs contents and lower lactose content in the milk from goats grazed on extensive pasture than in those fed on silage and hay.

The availability and accessibility to nutritive animal feed are financial and logistical challenges and are dependent on local and seasonal conditions and resources. Supplementation with, for example, oil seeds, vegetables and fish oils can enhance the nutritive value of feed available but the cost may deter its regular use in farming (Nkya *et al.*, 2002; Givens and Gibbs, 2008). Additionally, protein concentration and composition are less responsive to changes in animal nutrition except in extreme feeding conditions (Vera, Aguilar and Lira, 2009) or when using supplements; for example, organic selenium supplements may increase selenoprotein in milk (Walker, Dunshea and Doyle, 2004).

Lactation stage and milk composition

The patterns of change in protein and fat over the course of a lactation are similar in most species, and generally follow a trend opposite to the lactation curve (Gjøstein, Holand and Weladji, 2004; Riek and Gerken, 2006; Konuspayeva *et al.*, 2010). However, the changes in fat content are difficult to interpret, being strongly related to seasonal feeding effects (Shah *et al.*, 1983; Pikul and Wójtowski, 2008; Pikul *et al.*, 2008). The milk of wild and semi-domesticated ruminants is richer in both protein and fat in late lactation than in early lactation, in part to compensate for the declining rate of milk intake by the offspring during late lactation (Gjøstein, Holand and Weladji, 2004; Holand, Gjøstein and Nieminen, 2006). In contrast, some mare and donkey breeds have been reported to produce relatively dilute milk in mid to late lactation (Oftedal and Jenness, 1988; Ramljak *et al.*, 2009); both milk yield and in protein content declined as lactation progressed.

In general, there is an inverse relationship between ash content and lactose content in milk. Lactose together with sodium, potassium and chloride ions plays a major role in maintaining the osmotic pressure in the mammary system; thus, any increase or decrease in lactose is compensated for by an increase or decrease in the soluble salt constituents, reflected in the ash content (Fox and McSweeney, 1998). The ash content of most milks increases and the lactose content decreases with lactation stage (Ploumi, Belibasaki and Triantaphyllidis, 1998; Wangoh, Farah and Puhan, 1998; Sharma *et al.*, 2000; Gjøstein, Holand and Weladji, 2004; Zahraddeen, Butswat and Mbap, 2007), although the converse pattern has been observed in mare and donkey milks (Schryver *et al.*, 1986; Martuzzi *et al.*, 1997; Mariani *et al.*, 2001; Summer *et al.*, 2004; Santos *et al.*, 2005; Guo *et al.*, 2007; Santos and Silvestre, 2008) and ash and lactose contents do not vary significantly during lactation in some milks (Zhang *et al.*, 2005; Mech *et al.*, 2008). However, more complex patterns of change in lactose and ash have also been reported (Cerón-Muñoz *et al.*, 2002; Riek and Gerken, 2006; Konuspayeva *et al.*, 2010).

3.2.4 Nutritional value of milk from various species

Whole milk is seen to be a very good source of dietary fat, energy, protein and other nutrients (Table 3.6) when the average amounts of nutrients in various milks are compared with the *CODEX Guide to Food Labelling* (FAO and WHO, 2001). All

the milks listed in Table 3.6, except mare and donkey milks, are a source of protein. The high protein content of cow milk is one reason why unmodified cow milk is not recommended for infants less than 12 months old, although some studies suggest that mare and donkey milk may be appropriate for young children as they contain less protein and minerals and therefore present a lower renal load of solutes (Iacono *et al*., 1992; Malacarne *et al*., 2002). One cup (250 ml) of moose or reindeer milk provides the recommended safe level of protein intake (<26 g/day) for children less than 10 years of age (WHO, FAO and UNU, 2007).

None of the milks is a source of iron, which is the main reason why animal milks are not recommended in the complementary feeding of infants less than 12 months old. In addition, feeding animal milks to infants can lead to intestinal bleeding and loss of iron, as has been shown on studies on cow milk (Ziegler, 2007). The high calcium and casein contents in most milks also inhibit the absorption of dietary nonheme iron (Ziegler, 2007).

All the milks listed in Table 3.6 are sources of calcium, and most are high in calcium. All are low or very low in sodium. Moose milk contains significant amounts of selenium (11 µg/100 g), and even one cup (250 ml) provides the recommended nutrient intake (RNI) of 17 µg for a 1–3 year old child (FAO and WHO, 2002). Two cups of cow milk can also provide the RNI, based on the highest reported selenium content.

Buffalo, Bactrian camel and goat milks are sources of vitamin A (Table 3.6). Sheep milk is high in riboflavin while cow, goat, buffalo and Bactrian camel milks are adequate sources of riboflavin. The RNI of riboflavin, 0.5 mg/day, can be provided by two cups of cow, buffalo, goat, sheep or Bactrian camel milks. Buffalo milk is high in vitamin B_6, and two cups of buffalo milk a day (500 ml) can provide 330 percent of the RNI (0.5 mg/day) of vitamin B_6 for a 1–3 year-old child. Buffalo milk also contains biotin; even 100 g of buffalo milk can easily provide the RNI of 8 µg/day.

Sheep, mare and dromedary camel milks can be considered sources of vitamin C, containing an average of 4.6, 4.3 and 3.8 mg/100 g, respectively. The availability of even a moderate amount of vitamin C in camel milk has significant nutritional relevance in areas where green vegetables and fruits are hard to find (Sawaya *et al*., 1984, cited in Zhang *et al*., 2005). Bactrian camel milk is high in vitamin D, with two cups of milk providing 160 percent of the RNI (5 µg/day).

FAO and WHO (2010a) concluded that fats and FAs should be considered key nutrients: fats are energy dense (37 kJ or 9 kcal per gram), provide the medium for the absorption of fat-soluble vitamins and are crucial for embryonic development and early growth after birth, on through infancy and childhood (Burlingame *et al*., 2009). The report highlighted the negative effects of SFAs and *trans*-FA, and the positive effects of PUFAs, MUFAs and n-3 FAs. Individual SFA have different effects on the concentration of lipoprotein cholesterol fractions, with C12:0, C14:0 and C16:0 increasing low-density lipoprotein (LDL) cholesterol, while C18:0 has no effect (FAO and WHO, 2010a). The Expert Consultation (FAO and WHO, 2010a) concluded that there is convincing evidence that replacing SFA (C12:0 – C16:0) with PUFA decreases LDL cholesterol concentration and the total/high-density lipoprotein (HDL) cholesterol ratio. A similar but lesser effect is achieved by replacing these SFA with MUFA (FAO and WHO, 2010a).

TABLE 3.6
Nutritional claims for milk from various animals

	Conditions for nutrient claims* (per 100 g milk)	Cow	Buffalo	Goat	Sheep	Yak	Mare	Donkey	Dromedary camel	Bactrian camel	Mithun	Musk ox	Llama	Alpaca	Reindeer	Moose
	Not more than:															
Fat	Low 1.5 g						✓✓	✓✓								
Saturated fat	Low 750 mg						✓✓	✓✓								
Lactose	Low 0.5 g															✓
Sodium	Low 120 mg	✓✓	✓✓	✓✓	✓✓	✓✓			✓✓	✓✓	No data	No data		✓✓	✓✓	✓✓
	Very low 40 mg	✓		✓	✓	✓	✓✓	✓✓					✓✓			✓
	Conditions (per 100 g milk) Not less than:															
Protein	Source 2.5 g/ 100 g	✓✓	✓✓	✓✓			✓		✓✓	✓✓			✓✓			
	High 5 g/100 g				✓✓	✓✓					✓✓	✓✓		✓✓	✓✓	✓✓
Vitamin A	Source 60 µg/100 g		✓✓	✓		No data	No data	No data	No data	✓✓	No data	No data	No data	No data	No data	No data
Vitamin D	Source 0.375 µg/100 g		No data			No data	No data	No data	No data		No data	No data	No data	No data	No data	No data
	High 0.75 µg/100 g									✓✓						
Vitamin C	Source 4.5 mg/100 g				✓✓	No data	✓	No data	✓		No data	No data	No data	No data	No data	No data

TABLE 3.6 *(continued)*

	Conditions for nutrient claims* (per 100 g milk)	Cow	Buffalo	Goat	Sheep	Yak	Mare	Donkey	Dromedary camel	Bactrian camel	Mithun	Musk ox	Llama	Alpaca	Reindeer	Moose
Riboflavin	Source 0.12 mg/100 g	✓✓	✓✓	✓✓		No data				✓✓	No data	No data	No data	No data	No data	No data
	High 0.24 mg/100 g				✓✓											
Vitamin B_6	Source 0.15 mg/100 g					No data	No data	No data	No data		No data	No data	No data	No data	No data	No data
	High 0.3 mg/100 g		✓✓													
Vitamin B_{12}	Source 0.075 µg			✓✓		No data	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
	High 0.15 µg	✓✓	✓✓	✓	✓✓											
Calcium	Source 60 mg						✓✓	✓✓	✓✓		✓✓	No data		No data		
	High 120 mg	✓✓	✓✓	✓✓	✓✓	✓✓	✓		✓	✓✓			✓✓		✓✓	✓✓
Magnesium	Source 22.5 mg/100 g										No data	No data		No data		✓✓
Zinc	Source 1.1 mg/100 g					✓					No data	No data			✓✓	

*Based on the CODEX guide to food labelling (FAO and WHO, 2001). For protein, vitamins and minerals, the limiting conditions were calculated using the Nutrient Reference Values provided in the document.

No data: No information available

✓✓mean value meets condition

✓minimum (or maximum for protein, minerals and vitamins) value reported in literature meet condition

Cow, buffalo, goat and sheep milks all contain similar quantities of SFAs, 65–75 g/100 g total FA. Mare and donkey milks contain the lowest amounts of SFA, less than 40 g/100 g total FA in the case of mare milk. These two milks also contain the highest amount of PUFA, on average 20 g/100 g total FA. In addition, the indispensable FAs ALA and LA are present in equine milks.

Because of its high LA and ALA contents, mare milk has been suggested as ideal for pre-term infants, as their livers are probably capable of transforming these FAs into the n-3 FAs eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) and the n-6 FA arachidonic acid (Orlandoi, Goracci and Curadi, 2003). However, further studies are necessary, particularly with respect to effects on iron status in infants. For populations with no access to n-3 FA from fish, e.g. landlocked Mongolia, intake of mare milk is crucial for meeting requirements (adequate intake of 100–150 mg EPA+DHA for a 2–4-year-old child; acceptable macronutrient distribution range of 0.25–2 g/day for adults) (FAO and WHO, 2010a).

Trans-FA contents of up to 3–6 g/100 g total FA have been reported in cow, buffalo, goat, sheep, goat, reindeer and llama milks (LeDoux *et al*., 2002; Rodríguez-Alcalá, Harte and Fontecha, 2009). However, these values depend on the diet of the animals, with values up to 10 g/100 g total FA (or 0.33 g/100 g milk, given an average fat content of 3.5 g/100 g) being reported in cow milk under certain feeding regimes (Briard-Bion *et al*., 2008). No *trans*-FAs have been reported in donkey milk, while mare milk is reported to contain negligible amounts.

The most biologically active form of CLA is thought to be C18:2 *cis*-9, *trans*-11 (c9, t11-CLA) (Jensen, 2002), which represents more than 90 percent of CLA in ruminant milk fat (Savoini *et al*., 2010). C18:1 *trans*-11 (vaccenic acid), the dominant *trans*-FA in products of ruminant origin, can be desaturated in the body and converted to CLA.[13]

Cow milk is reported to contain between 0.1 and 2.2 g of CLA/100 g total FA, the amount varying with various factors including feed, with values as high as 3.3 g/100 g total FA reported in milk from grass fed cows (Jutzeler van Wijlen and Colombani, 2010). Sheep milk is reported to contain more CLA than cow and goat milks (Jahreis *et al*., 1999; Tsiplakou *et al*., 2009), which may be partially attributed to the semi-extensive nature of sheep farming (Sanz Sampelayo *et al*., 2007). Buffalo milk contains an amount of CLA similar to or greater than that in cow milk. Mare (monogastric), llama and Bactrian camel (pseudo-ruminant) and yak (ruminant) milks have been reported to contain only very small amounts of CLA. The CLA content in human milk is reported to vary from 0.2 to 1.1 g/100 g total FA (Malacarne *et al*., 2002).

3.3 TREATED LIQUID MILKS AND DAIRY PRODUCTS

Very little raw milk (i.e., "milk which has not been heated beyond 40 °C or undergone any treatment that has an equivalent effect") is now drunk (FAO and WHO, 2009). The hazards and risks associated with the consumption of raw milk are discussed in Chapter 6.

[13] The health impact of CLA and *trans*-FA are considered in Chapter 5. Chapter 5 also highlights the labelling classifications of CLA.

The earliest milk products were developed to conserve the principal constituents of milk in periods of surplus production. For example, nomadic people in Outer Mongolia process most of the milk they obtain in the short summer season into fermented milk, butter, and dried fermented milk products, some of which have very long or indefinite shelf-lives and can be used in the winter when fresh milk is sometimes unavailable (Orskov, 1995). Milk products are also easier to transport than liquid milk, a major consideration for nomadic herders; it is common for a family of herders in Outer Mongolia to move 6–12 times a year (Orskov, 1995). Milk products are also a means of diversifying the diet for these people. Milk products can also reach more distant markets: in some parts of the world, there has been a recent increase in demand for gourmet products from various milks (Holand *et al.*, 2002). Products can be tailored to meet consumer demands and attract a higher price than raw milk.

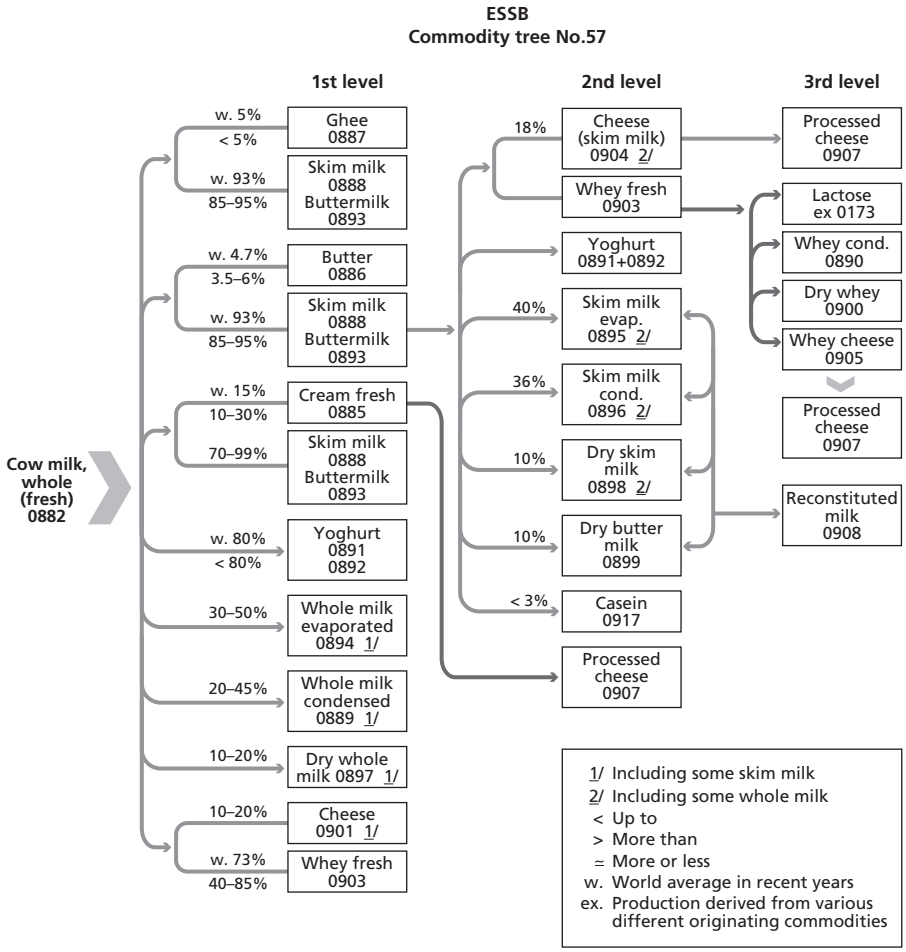
A fascinating account of the history of cheese-making is given by Fox and McSweeney (2004). The authors report that coagulation of milk by the *in situ* production of lactic acid was probably accidental, as lactic acid bacteria have the ability to grow in milk and produce enough acid to lower the pH of milk, causing the milk proteins to coagulate. Similarly, the use of rennets to coagulate milk may also have initially been accidental: before the development of pottery (~5000 BC), milk was commonly stored in bags made from the stomachs of slaughtered animals. Enzymes (chymosin and some pepsin) in the stomach tissue would have caused the milk to coagulate on storage. People would then have come to realize that the shelf-life of the curds could be extended by dehydration or by adding salts.

Figure 3.3 shows the dairy commodity tree, a symbolic representation of the flow from a primary commodity to various processed products derived from it, together with the conversion factors from one commodity to another. For example, the extraction rate[14] for butter from whole milk is 4.7 percent, while it is 93 percent for butter from skimmed milk (first level processing). The skimmed milk can be converted into a range of products (second level), including skimmed-milk cheese (extraction rate 18 percent) and fresh whey, evaporated skimmed milk (extraction rate 40 percent), condensed skimmed milk (extraction rate 36 percent) and dry skimmed milk (extraction rate 10 percent). Some of these products can be further processed to give further products (third level), such as processed cheese from skimmed-milk cheese. When you consider that the products formed can vary with milk source (cow, buffalo, goat etc., although not all products are possible with all milks) and the large range of varying products present within some of these categories (e.g. cheese), an idea of the vast number of dairy products available is obtained. However, the majority of published research concerns cheese and fermented milk products, with particular emphasis on the microbiology of these products.

Table 3.7 shows the composition of some of these products, excluding cheese.

[14] Extraction rate relates to processed products only and indicates, in percent terms, the amount of the processed product concerned obtained from the processing of the parent/originating product, in most cases a primary product.

FIGURE 3.3
Dairy commodity tree



Source: FAO, undated.

3.3.1 Milk classifications

Milk can be classified according to its fat content, for example as whole milk, skimmed milk, semi-skimmed milk, low-fat milk and standardized milk. It can also be classified according to the processing procedures it has undergone, such as pasteurized milk, sterilized milk, extended shelf-life (ESL) milk and ultra-high-temperature (UHT)-treated milk, among others. The FAOSTAT definitions for various milk and milk products are given below in italics, where available. The FAOSTAT codes are given within brackets. CODEX definitions are given only where FAOSTAT definitions are not available or where additional information is needed.

TABLE 3.7
Composition of milk products excluding cheese (per 100 g of product)

FAOSTAT code	Description	Water (g)	Energy (kcal)	Energy (kJ)	Protein (g)	Total fat (g)	Lactose (g)
882	Cow milk, whole, fresh	88.1	61	256	3.2	3.3	5.1
885	Cream, fresh	73.8	195	818	2.7	19.3	0.1
886	Butter of cow milk	15.9	717	2 999	0.9	81.1	0.1
887	Ghee (from cow milk)	0.2	876	3 664	0.3	99.5	0.0
888	Skim milk of cows	90.8	34	142	3.4	0.1	5.1
889	Whole milk, condensed	27.2	321	1 343	7.9	8.7	54.4
891	Yoghurt	87.9	61	257	3.5	3.3	4.7
894	Whole milk, evaporated	74.0	135	567	6.8	7.6	10.0
895	Skim milk, evaporated	79.4	78	326	7.6	0.2	11.4
897	Dry whole cow milk	2.5	496	2 075	26.3	26.7	38.4
898	Dry skim cow milk	3.2	362	1 516	36.2	0.8	52.0
900	Dry whey	3.4	346	1 448	12.3	0.8	74.0
903	Whey, fresh	93.3	26	107	0.8	0.2	5.1

Data source: Merrill and Watt, 1973. For energy, specific Atwater factors have been used by USDA, 2009. Cow milk, whole, fresh – food code 01211, Milk, whole, 3.25% milkfat, without added vitamin A and vitamin D; Cream, fresh – food code 01050, Cream, fluid, light (coffee cream or table cream); 01001, Butter of cow milk – food code Butter, salted; Ghee (from cow milk) – food code 01003 Butter oil, anhydrous; Skim milk of cows – food code 01151 Milk, nonfat, fluid, without added vitamin A and vitamin D (fat free or skim); Whole milk, condensed – food code 01095 Milk, canned, condensed, sweetened; yoghurt – food code 01116 Yoghurt, plain, whole milk, 8 grams protein per 8 ounce; Whole milk, evaporated – food code 01214, Milk, canned, evaporated, without added vitamin A and vitamin D; Skim milk, evaporated – food code 01097, Milk, canned, evaporated, nonfat, with added vitamin A and vitamin D; Dry whole cow milk – food code 01090, Milk, dry, whole, with added vitamin D; Dry skim cow milk – food code 01091, Milk, dry, nonfat, regular, without added vitamin A and vitamin D; Dry whey – calculated average of food codes 01112, Whey, acid, fluid and 01114, Whey, sweet, fluid; Whey, fresh – calculated average of food codes 01113, Whey, acid, dried and 01115, Whey, sweet, dried.

Liquid milk

Cow milk, whole, fresh (0882): *Production data refer to raw milk containing all its constituents. Trade data normally cover milk from any animal (e.g., buffalo [0951], goat [1020], sheep [0982], camel [1130]) and refer to milk that is not concentrated, pasteurized, sterilized or other-wise preserved, homogenized or peptonized.*

Milk skim of cows (0888): *Milk from which most of the fat has been removed.* Can be applied to milk from other animals too, such as buffalo (0954), sheep (0985) and goat (1023).

Skimmed milk (also known as "fat free" or "non-fat" milk) contains reduced amounts of fat-soluble vitamins, particularly vitamin A, compared with whole milk.

Standardized milk (0883): *Milk in which the fat content is adjusted to a predetermined value without altering any other constituents.*

Standardizing is usually carried out either by incomplete skimming of whole milk to remove part of the fat, or by mixing the whole milk with skimmed milk.

Reconstituted milk (0908): *Obtained by adding water, fat, etc. to milk powder.*

Fortified milks: Milk can be enriched with various compounds to increase the intake of particular micronutrients, for example vitamins A, D and C and iron.[15] Some authors argue that milk can play an important role as a vector of supplements: the complexity and nutritional stability of milk makes it an ideal vehicle for providing important trace nutrients that can improve nutritional quality and prevent chronic degenerative diseases (Arsenio *et al.*, 2010).

Condensed milk

Condensed milk may be sweetened or unsweetened, and made from whole or skimmed milk.

Whole milk, condensed (0889): *Milk and cream from which water has been partly removed after heat-treating and concentrating. Normally sucrose is added to give the product stability and bacteriological safety.*

Skim milk, condensed (0896): *Same as above (0889), but applied to skim milk.*

According to the *CODEX standard for sweetened condensed milks* (FAO and WHO, 2010b), sweetened condensed milk should contain a minimum of 8 percent milk fat m/m (where percent m/m [mass per mass] is equivalent to percent by weight) and minimum of 34 percent milk protein in milk solids-not-fat m/m. Sweetened condensed skimmed milk should contain a maximum of 1 percent milk fat m/m and a minimum of 34 percent milk protein in milk solids-not-fat m/m. Sweetened condensed high-fat milk should contain a minimum of 16 percent milk fat m/m and a minimum of 34 percent milk protein in milk solids-not-fat m/m.

Sweetened condensed milk is a high-solids milk product, about 45 percent of the solids consisting of sucrose (Williams, 2002). It is also high in energy (1 343 kJ or 321 kcal/100 g) (Table 3.7). The high sucrose:water ratio gives the product a long shelf-life because it inhibits the growth of micro-organisms. This removes the need for high-heat treatment during manufacture, and condensed milk is not sterilized. Nutrient losses on production are comparable to those occurring on pasteurization, as discussed in Section 3.3.2.

Dehydrated milk products

Evaporated milks

Whole milk, evaporated (0894): *Milk and cream from which the water has been partly removed and which has been heat- treated to render it bacteriologically safe and stable.*

Skim milk, evaporated (0895): *Same as 0894 (above), but applied to skim milk.*

FAO and WHO (2010c) sets the following standards for evaporated milks:

- evaporated milk – minimum milk fat 7.5 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m

[15] Fortified milks are covered in Chapter 5.

- evaporated skimmed milk – maximum milk fat 1 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m
- evaporated partly skimmed milk – milk fat content between 1 and 7.5 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m
- evaporated high-fat milk – minimum milk fat 15 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m.

Evaporated milk products are sterilized in their retail containers (120 °C/13 minutes) (Williams, 2002), and nutrient loss will occur, as discussed in Section 3.3.2.

Dry milk/milk powder

Milk whole dried (0897): *Milk and cream from which water has been completely removed by various methods. In form of powder, granules or other solid forms. May contain added sugar or other sweeteners.*

Milk skimmed dried (0898): *Same as 0897, but from skim milk. Normally does not exceed 1.5 percent fat content.*

The *CODEX standard for milk powders and cream powder* (FAO and WHO, 2010d) sets out the following standards for milk and cream powders:

- whole milk powder – minimum 26 percent milk fat, maximum 42 percent m/m; maximum water 5 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m
- partly skimmed milk powder – milk fat more than 1.5 percent and less than 26 percent m/m; maximum water 5 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m
- skimmed-milk powder – maximum milk fat 1.5 percent m/m; maximum water 5 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m
- cream powder – minimum milk fat 42 percent m/m; maximum water 5 percent m/m; minimum milk protein in milk solids-not-fat 34 percent m/m.

Milk powders reflect the composition of the original milks from which they are made (see, for example, Marconi and Panfili, 1998).

Dry whole milk has a short shelf-life because the fat becomes rancid easily, whereas dried skimmed milk (skimmed-milk powder), because of its lower fat content, has a shelf-life of about three years if stored in cool conditions with low humidity (Hoppe *et al.*, 2008).

Dry whey (0900): *Used in both food and animal feed.*

Whey is the liquid part of milk that remains after the casein has coagulated in cheese production.

The *CODEX standard for whey powders* (FAO and WHO, 2010e) requires the following composition for whey powder:

- lactose – reference content 61.0 percent (m/m)
- milk protein – minimum content 10.0 percent (m/m)
- milk fat – reference content 2.0 percent (m/m)
- water – maximum content 5.0 percent (m/m)
- ash – maximum content 9.5 percent (m/m).

Dry buttermilk (0899): no definition given.

Nutrient profile of milk powder

The heat treatment involved in drying results in denaturation of milk whey proteins and formation of whey protein–casein protein aggregates. The heat treatments are also associated with the loss of vitamins. Sharma and Lal (2002), for example, found that skimmed-milk powder made from buffalo milk contained 12 percent less thiamine, 10 percent less riboflavin, 13 percent less vitamin B_6, 16 percent less folate and 19 percent less total vitamin C than the original milk and that losses of water-soluble vitamins continued during storage in sealed polyethylene bags.

Marconi and Panfili (1998) showed that while some of the characteristics of mare milk were retained in milk powder (e.g. high whey protein, low casein, high PUFA, particularly C18:2 and C18:3), other nutrients were partly or completely destroyed: these include lysine (12 percent loss), vitamin A (RE) (40 percent loss), tocopherols (60 percent loss), riboflavin (100 percent loss) and vitamin C (96 percent loss). Similar losses were observed in cow milk powder prepared by spray-dried process: lysine (5 percent loss), vitamin A (RE) (60 percent loss), tocopherols (40 percent loss), riboflavin (30 percent loss) and vitamin C (93 percent loss).

3.3.2 Heat treatments and microbiocidal measures

FAO and WHO (2009) gives the following definitions for various heat-treatments or microbiocidal measures carried out on milk:

Thermization: "The application to milk of a heat treatment of a lower intensity than pasteurization that aims at reducing the number of micro-organisms. A general reduction of log 3–4 can be expected. Micro-organisms surviving will be heat-stressed and become more vulnerable to subsequent microbiological control measures".

Thermization heat treatments can range from heating at 52–67 °C for between 20 seconds and about half an hour (Valdramidis *et al*., 2011). Thermization is the heating of raw milk for at least 15 seconds at a temperature between 57 °C and 68 °C such that after treatment the milk shows a positive reaction to the phosphate test (CEC, 1992).

Pasteurization: "Pasteurization is a microbiocidal heat treatment aimed at reducing the number of any pathogenic micro-organisms in milk and liquid milk products, if present, to a level at which they do not constitute a significant health hazard. Pasteurization conditions are designed to effectively destroy the organisms *Mycobacterium tuberculosis* and *Coxiella burnettii*".

The process criteria are given as the following: "According to validations carried out on whole milk, the minimum pasteurization conditions are those having bactericidal effects equivalent to heating every particle of the milk to 72 °C for 15 seconds (continuous flow pasteurization) or 63 °C for 30 minutes (batch pasteurization)".

UHT (ultra-high temperature) treatment: UHT treatment of milk and liquid milk products "is the application of heat to a continuously flowing product using such high temperatures for such time that renders the product commercially sterile

at the time of processing. When the UHT treatment is combined with aseptic packaging, it results in a commercially sterile product".

The process criteria are reported to be the following: "UHT treatment is normally in the range of 135 to 150 °C in combination with appropriate holding times necessary to achieve commercial sterility. Other equivalent conditions can be established through consultation with an official or officially recognized authority. Validation of milk flow and holding time is critical prior to operation".

Typical UHT heating times are 2–10 seconds at 135–150 °C (Montilla, Moreno and Olano, 2005). Although UHT milk used to be mainly cow milk, recently other UHT milks have become available in several countries, such as UHT goat milk in the UK and Italy and UHT buffalo milk in India, UK and Egypt.

Commercial sterilization: "The application of heat at high temperatures for a time sufficient to render milk or milk products commercially sterile, thus resulting in products that are safe and microbiological stable at room temperature".

The typical condition for sterilizing milk is heating at 110–140 °C for 20–30 minutes (Montilla, Moreno and Olano, 2005).

Impact of heat treatment and storage on the nutrient profile of milk

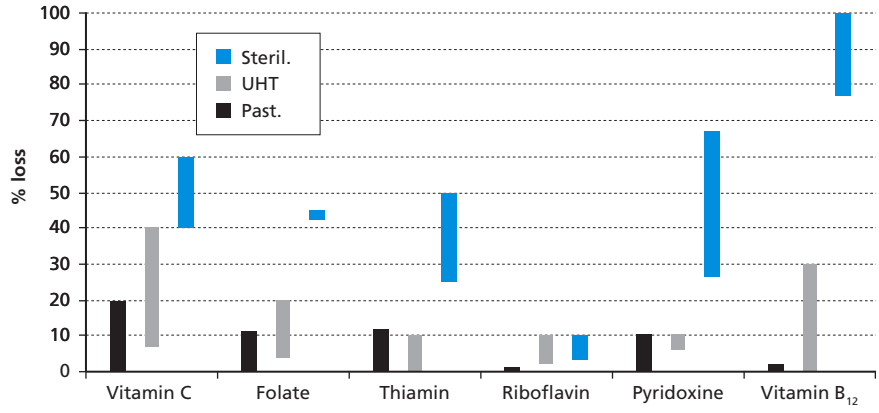
The literature mainly covers the effects of pasteurization or UHT treatment on milk composition. Few studies are available on sterilization, and these generally concern infant formula. The main effects of heat treatment that are of nutritional significance are: (i) degradation of vitamins; (ii) denaturation of whey proteins (which can be beneficial, improving protein digestibility and decreasing their allergenic properties); (iii) Maillard reactions between reducing sugars and the epsilon amino groups of lysine residues in proteins; and (iv) reactions of lactose. These effects are discussed below.

Degradation of vitamins

The effects of heat processing and storage on water-soluble vitamins in milk have been well-documented, although most studies are fairly old. Vitamin C is particularly prone to degradation during processing because of its high susceptibility to oxidation in the presence of oxygen and metal ions, and to degradation during heat treatment (Gliguem and Birlouez-Aragon, 2005). Other factors that influence the nature of the degradation mechanism of vitamin C are salt and sugar concentrations, pH, enzymes, the initial concentration of ascorbic acid and the ratio of ascorbic acid to dehydroascorbic acid (Andersson and Öste, 1994). Riboflavin is very sensitive to light and UV radiation but relatively stable to heat and atmospheric oxygen. Thiamine is sensitive to heat and alkaline conditions.

Losses in vitamin C, folate and vitamin B_{12} increase with increased severity of treatment, and sterilization caused significant losses of all vitamins shown above except riboflavin (Figure 3.4). Vitamin C degradation is particularly influenced by the presence of dissolved oxygen in milk: when milk was UHT treated without degassing, 82 percent of the ascorbic content was lost (Andersson and Öste, 1994). Several studies looked at the effect of packaging materials and storage conditions on vitamin stability. Vitamin C content of raw and heat treated milks decreased significantly even during storage for two weeks in a freezer. It is important to note that degradation during storage occurs even in vitamin C-fortified milk (semi-skimmed

FIGURE 3.4
Loss of vitamins in milk associated with various heat treatments



Sources: Sharma and Lal, 1998: Pasteurization at 63 °C for 30 minutes and sterilization at 121 °C for 15 minutes; Andersson and Öste, 1994: data for average values or most commonly reported values. Various conditions, including pasteurization at 72–75 °C for 15–20 seconds, pasteurization at 90–92 °C for 2–3 seconds; direct and indirect UHT treatment; Burton *et al.*, 1970: UHT sterilization at 144 °C for direct heating and 141 °C for indirect heating; Haddad and Loewenstein, 1983: pasteurization at 72 °C for 16 seconds and 80 °C for 16 seconds, UHT sterilization at 110 °C for 3.5 seconds and 140 °C for 3.5 seconds. References cited in Asadullah *et al.*, 2010: sterilization at 143 °C for 3–4 seconds; in-bottle sterilization at 120 °C for 13 minutes.

cow milk, fortified with 256 mg of vitamin C/litre) subjected to heat treatment: after 1 month in storage, 51–99 percent of vitamin C had been degraded (Gliguem and Birlouez-Aragon, 2005). The almost total loss of vitamin C on storage (either UHT-processed or in-bottle sterilized) occurred when three-layered packaging was used, while 51 percent degradation occurred with six-layered packaging (Gliguem and Birlouez-Aragon, 2005).

Not more than 10 percent loss in riboflavin was reported, independent of heat treatments used. Niacin and pantothenic acid were reported to be relatively stable during UHT treatment (<10 percent being lost), while biotin was stable during both UHT treatment and subsequent storage for 90 days at 15–19 °C (Ford *et al.*, 1969).

Andersson and Öste (1994) reported no appreciable losses of fat soluble vitamins A, D and E after pasteurization (72 °C, 15 seconds) or UHT treatment, although losses of vitamin A were appreciable in storage.

Denaturation of whey proteins

Whey protein denaturation was reported to be higher in in-bottle-sterilized milk than in UHT milk (Gliguem and Birlouez-Aragon, 2005) while protein denaturation was reported to be much lower in pasteurized milk (0.4 percent) than in UHT milk (56 percent) (Andersson and Öste, 1994). β-lactoglobulin and κ-casein aggregate during heat treatment, reducing the solubility of milk proteins.

Maillard reactions

Some studies looked at the antioxidant stability of milk and the modification of milk proteins by the Maillard reaction (Van Boekel, 1998; Calligaris *et al.*, 2004;

Hedegaard *et al*., 2006; Smet *et al*., 2009; Hiller and Lorenzen, 2010), where mainly lysine residues in casein react with lactose and other sugars (Gliguem and Birlouez-Aragon, 2005). Maillard reactions lead to browning of milk, associated with the formation of brown melanoidins. No Maillard reactions are expected to occur during pasteurization (Andersson and Öste, 1994). Even UHT treatment causes only very small losses of lysine, ranging from 0–5 percent (Andersson and Öste, 1994). One study involved powdered infant formulas sterilized by autoclaving for 5 minutes at 105 °C and 5 600 kg/m^2 of pressure after being reconstituted with hot water (80 °C) (Yeung *et al*., 2006). The authors reported a 20 percent reduction in total protein after autoclaving compared with conventional preparation. Concentrations of total free amino acids were significantly lower (P = 0.01) and individual amino acids were lower in autoclaved infant formulas. In particular, losses in valine (72 percent), glutamine (60 percent) and lysine (40 percent) were noted. The concentration of ammonia was significantly higher (P = 0.0003) after autoclaving, and may reflect degradation of protein and amino acids (Yeung *et al*., 2006).

Reactions of lactose

Heat treatment of milk results in isomerization of part of the lactose to lactulose (Zhang *et al*., 2010). Lactulose is reported to stimulate the growth of bifidobacteria (Zhang *et al*., 2010). The amount of lactulose formed depends on the extent of heat-treatment, with the lactulose content sometimes being used as a measure of the extent of heat-treatment (Montilla, Moreno and Olano, 2005). Lactulose contents in commercial samples purchased from local stores ranged between 1.3 and 3.2 mg/100 g of pasteurized milk, 9.5 and 43.7 mg/100 g of UHT milk and 62 and 71 mg/100 g of sterilized milk (Montilla, Moreno and Olano, 2005). Reconstituted milk powder was found to contain only 2.4–4.9 mg of lactulose /100 g, the low values reflecting the milder processing conditions to which milk powder is subjected, and the slower isomerization in the solid state.

Other effects

Heat treatment would also be expected to cause isomerization of certain FAs. Herzallah, Humeid and Al-Ismail (2005) found that pasteurization (63 °C for 30 minutes) increased the *trans*-isomer content of milk by 31 percent but that the higher temperature (but shorter duration) involved in UHT treatment did not result in significant (P < 0.05) increases in *trans*-isomer content. Siddique *et al*. (2010) found that different UHT processing temperatures and storage temperatures had no influence on ash content.

Conclusions

It is clear that although heat treatment is essential to ensure total microbiological safety, it also reduces various nutrient contents, and some of these losses are compounded by storage. A study of semi-skimmed cow milk and fortified milk subjected to UHT (135 °C, 3–4 seconds) treatment or in-bottle sterilization (110 °C, 20 minutes), stored in different packaging for various storage periods (3 days, 1, 2 and 4 months) concluded that "a radical modification of the milk composition occurs during storage, which aggravates the changes firstly induced by the sterilization heat treatment. Optimal quality would require UHT (treatment), packaging in

6-layered opaque bottles, and storage at a low temperature (<20 °C) or for a limited time (<2 months)" (Gliguem and Birlouez-Aragon, 2005).

3.3.3 Fermented milk products

There are more than 3 500 traditional, fermented foods worldwide (EUFIC, 1999). Fermented milk products have been reported to have a positive effect on the human digestive system and are also implicated in the control of serum cholesterol, as discussed in Chapter 5.

Both milk protein and lactose in fermented milk are more easily digestible than those in the original milk. Proteins are partly degraded by the action of the bacterial proteolytic system. The lactose content is lower than in the parent milk, as part of it is converted to lactic acid and/or alcohol. Lactic acid gives rise to the characteristic sour taste associated with fermented products. Yoghurt and fermented milks may contain more folate than the original milk because some strains of lactic acid bacteria also synthesize folate (Wouters *et al.*, 2002). Fermentation not only makes milk more digestible, but is also a means of increasing the shelf-life and microbiological safety of the products.

Fermented milks

Buttermilk, curdled, acidified milk (0893): *Residue from butter making. Includes kephir.*

The *CODEX standard for fermented milks* (FAO and WHO, 2010f) defines fermented milk as "a milk product obtained by fermentation of milk, which milk may have been manufactured from products obtained from milk with or without compositional modification … by the action of suitable micro-organisms and resulting in reduction of pH with or without coagulation (isoelectric precipitation). These starter micro-organisms shall be viable, active and abundant in the product to the date of minimum durability. If the product is heat-treated after fermentation the requirement for viable micro-organisms does not apply." The standard specifies a minimum milk protein content of 2.7 percent m/m, and a milk fat content of less than 10 percent m/m. The CODEX standard also includes yoghurt and alternate culture yoghurt.[16]

Although about 400 generic names are applied to fermented milks around the world, the real number of distinct products is much smaller (Khurana and Kanawjia, 2007). Robinson and Tamime (1995), cited in Khurana and Kanawjia (2007), proposed a classification scheme that classifies fermented milks according to the type of fermentation: a) lactic fermentations (with mesophilic-, thermophilic-, therapeutic- or probiotic-type fermentations); b) yeast–lactic fermentations; and c) mould–lactic fermentations). A few of the more widely-studied fermented milk products are discussed below.

[16] Codex Alimentarius (standard 243-2003) characterizes fermented milks by specific starter culture(s) used for fermentation. Yoghurt: symbiotic cultures of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*; alternate culture yoghurt: cultures of *Streptococcus thermophilus* and any *Lactobacillus* species.

Kephir (kefir)

Kephir is a viscous, highly acidic beverage produced from cow, goat, sheep or mare milks which can contain various amounts of alcohol and carbon dioxide (Sarkar, 2007; Ribeiro and Ribeiro, 2010). The fermentation is initiated by "kephir grains" (clusters of yeast and bacteria), which are added to milk; hence, kephir belongs to the yeast–lactic fermentation category. Kephir is made from raw, pasteurized or UHT-treated milk. The milk is poured into a clean container, the kephir grains are added and the milk is left to stand for about 24 h. The milk is then filtered to retrieve the kephir grains, which are used to produce the next batch of kephir. The grains are passed from generation to generation in households in the Caucasus, where they are considered a source of family wealth (Lopitz-Otsoa *et al*., 2006).

While kephir is produced commercially in many countries, particularly in Eastern Europe, it is made in homes in countries as widespread as Argentina, France, Portugal, Taiwan and Turkey (Farnworth, 2005, cited in Ribeiro and Ribeiro, 2010). Kephir has both therapeutic attributes and nutritional attributes, such as high contents of thiamine, riboflavin, pantothenic acid and vitamin C (the vitamin content varying with milk source and supplementary flora), protein (with a higher protein content when kephir grains were cultured in whey or soy milk) and minerals (Sarkar, 2007). Kephir also contains greater amounts of threonine, serine, alanine and lysine than does milk (Guzel-Seydim *et al*., 2003, cited in Sarkar, 2007).

According to the *CODEX standard for fermented milks* (FAO and WHO, 2010f), kephir should contain a minimum of 2.7 percent milk protein m/m and less than 10 percent milk fat m/m.

Kumys (kumiss, koumiss)

This fermented product, generally made from equine or goat milk, is consumed in Russia and western Asia primarily for its therapeutic value. Equine milk cannot be used to produce cheese as no curd is formed on addition of rennet. However, it forms a weak coagulum under acidic conditions and this is exploited in the production of yoghurt-type products such as kumys (Uniacke-Lowe, Huppertz and Fox, 2010). In Mongolia, kumys, called *airag*, is the national drink and distilled kumys, *arkhi*, is also produced (Kanbe, 1992, and Ørskov, 1995, cited in Uniacke-Lowe, Huppertz and Fox, 2010). Kumys belongs to the yeast–lactic fermentation group, where alcoholic fermentation using yeasts is used in combination with lactic-acid fermentation (Tamine and Marshall, 1984, cited in Uniacke-Lowe, Huppertz and Fox, 2010). Kumys contains about 90 g of moisture /100 g, 2.1 g of protein /100 g (1.2 g of casein /100 g and 0.9 g of whey proteins/100 g), 5.5 g of lactose/100 g, 1.2 g of fat/100 g and 0.3 g of ash/100 g, as well as the end-products of microbial fermentation, i.e. lactic acid (1.8 g/100 g), ethanol (0.6–2.5 g/100 g) and CO_2 (0.5–0.9 g/100 g) (Uniacke-Lowe, Huppertz and Fox, 2010). Up to 10 percent of the equine milk proteins are reported to be hydrolysed after 96 hours (Berlin, 1962 cited by Uniacke-Lowe, Huppertz and Fox, 2010; Tamine and Marshall, 1984, cited by Uniacke-Lowe, Huppertz and Fox, 2010). Kumys is thought to be more effective than raw equine milk in the treatment of various illnesses because it contains additional peptides and bactericidal substances from microbial metabolism (Doreau and Martin-Rosset, 2002, cited in Uniacke-Lowe, Huppertz and Fox, 2010). According to the *CODEX standard for fermented milks* (FAO and WHO, 2010f), kumys should contain less than 10 percent milk fat m/m.

Tarag

This traditional naturally-fermented goat milk from China forms part of the staple diet of the Mongolian community, who reportedly consume 1–2 litres of tarag per person per day (Zhang *et al*., 2009). According to these authors, in this region, tarag is produced using the raw whole milk from the Zang and Chaidamu breeds of goats. The raw milk is put into a big leather bag, tied with a leather string, and left for at least two days at 15–20 ºC, during which time the natural fermentation occurs. The authors analysed 10 authentic tarag samples collected from households. They reported average values of 4.6 g of fat/100 g, 5.6 g of protein/100 g and 2.0 g of lactose/100 g. Although they do not present the composition of the original milks, the protein content is considerably higher than average values reported for goat milk, and the lactose content is lower than in goat milk. The authors comment on the high calcium (181 mg/100 g) and phosphorus (187 mg/100 g) contents in tarag. However, the vitamin C content in tarag (1.4 mg/100 g) is reported to be less than that of milk, the average vitamin C in goat milk in this region being very high (12 mg/100 g) (Zhang *et al*., 2009). Although tarag is reported to be rich in proteins (casein, lactoferrin, serum albumin, β-lactoglobulin, α-lactalbumin) (Zhang *et al*., 2009), no values are given.

Kurut

Kurut is a fermented yak milk from China. It is reported to be rich in protein and fat: average fat 5.4 g/100 ml, total protein 5.4 g/100 g, lactose 2.3 g/100 g and ash 0.9 g/100 g (Zhang *et al*., 2009). Lactose in yak milk can vary between 3.3–6.2 g/100 g. The low lactose content in kurut has been ascribed to the strength and length of fermentation of lactose by lactic acid bacteria and yeast during production. The authors reported that the average vitamin C content was much lower in kurut samples than in yak milk (1.74 mg/100 g compared with 15 mg/100 g) due to oxidation. Nevertheless, the authors conclude that kurut is an important source of vitamins for the Qinghai people, whose diet does not include much fruit or grain. Microbiological analysis revealed that the kurut contained higher lactic acid bacteria and yeast counts than those of other traditional fermented milks such as airag (mare milk), kumys (mare milk) and kephir (cow milk).

Other fermented milks

Other traditional fermented milk products include *lassi* (buffalo, cow) and *shrikhand* or *chakka* (Afghanistan and India, from cow, sheep and goat milk); *taette* or Lapp's milk (Scandinavia, cow); *roub* and *mish* (Sudan, cow); *kule naoto* (Kenya, cow); *suusac* (Kenya, camel); acidophilus milk (Australia, various milks); cultured buttermilk (Scandinavian and European countries, from cow milk), *laban, leben* and *labneh* (Lebanon, Arab countries, from cow, sheep and or goat milk), *xynogalo* (Greece, sheep); *ymer* (Denmark, cow) and *shubat* (Kazakhstan, camel). An extensive list of products, together with the milk used and microflora utilized, can be found in literature (e.g. Litopoulou-Tzanetaki and Tzanetakis, 1999; Khurana and Kanawjia, 2007; Zhang *et al.*, 2009).

Yoghurt

Yoghurt (0891): *A fermented milk food.*
Yoghurt, concentrated or unconcentrated (0892): *Includes additives such as sugar, flavouring materials, fruit or cocoa.*

Yoghurt is produced by lowering the pH of milk proteins to their isoelectric points (about pH 4.6) by the fermentation of lactose to lactic acid using starter bacteria. Yoghurts can be differentiated according to the fat content of the milk used to produce the yoghurt (non-fat, low-fat or whole milk), the milk source (e.g. cow, buffalo, goat or sheep milks; for example, traditional Greek yoghurt is produced with full fat sheep milk) and processing (e.g. UHT-treated yoghurt, fruit-flavoured yoghurt, yoghurt drinks, smoothies and whipped or aerated yoghurt).

The milk used for yoghurt production varies, including milk concentrated by evaporation or filtration, by supplementing milk with milk powders or by reconstituting milk powders directly to the desired concentration (Tamime and Robinson 1999, cited in Williams, 2002). The milk is homogenized and heat-treated, with typical heat treatments being 85 °C for 30 minutes or 95 °C for 5 minutes. The milk is then cooled to 42 °C, inoculated with cultures and incubated at 42 °C for about 4.5 h, until the pH decreases (Williams, 2002). The heating step leads to denaturation of whey proteins. These proteins, together with the caseins, precipitate at low pH, leading to the properties associated with yoghurt. According to the *CODEX standard for fermented milks* (FAO and WHO, 2010f), yoghurt, alternate culture yoghurt and acidophilus milk should contain a minimum of 2.7 percent milk protein m/m and less than 15 percent milk fat m/m. The composition of generic yoghurt is given in Table 3.7.

Dahi (dadhi)

According to some estimates, about 7 percent of all milk produced in India is used to prepare the traditional fermented milk product dahi (curd, which is equivalent to yoghurt), intended for direct consumption (Sarkar, 2008). This is significant, considering that India is now the largest milk producing country in the world. Although dahi is an age-old indigenous fermented milk product, it has managed to retain its popularity and remain part of the Indian diet despite changing lifestyles and food habits (Khurana and Kanawjia, 2007). In Bangladesh, about 4 percent of milk is made into dahi (Nahar *et al.*, 2007). Dahi is further converted into shrikhand (or chakka, a sweetened concentrated curd) and lassi (stirred curd).

Dahi is reported to be very nutritious, and possess various therapeutic properties (Nahar *et al.*, 2007; Sarkar, 2008). In one study where authors produced dahi from cow, buffalo and goat milks on a lab scale (Nahar *et al.*, 2007), protein content was reported to be 3.8, 4.3 and 3.3 g/100 g for cow-, buffalo- and goat-milk dahi, respectively. Fat content was reported to be 4.0, 7.8 and 3.7 g/100 g of dahi produced from cow, buffalo and goat milks. Values for ash were 0.8, 1.0 and 0.8 g/100 g, respectively. These values are broadly consistent with the protein, fat and ash contents of the original milks (Table 3.1). Lactose content of dahi is significantly lower than that of the parent milk (Boghra and Mathur, 2000). During the production of dahi, folate increases by 165–331 percent and riboflavin and niacin by 160–201 percent; however, when dahi is converted to chakka some of these vitamins are lost (Atreja and Deodhar, 1987, cited in Sarkar, 2008). The protein quality of dahi is reported to be higher than that of milk.

3.3.4 Cheese

Nearly 52 percent of the world's cheese is produced in Europe (Table 3.8), although the biggest single producer is the United States. Only 7.7 percent of cheese is produced by Low Income Food Deficit Countries, while less than 2 percent of the world production is from Least Developed Countries, which shows that cheese is not a major source of nutrients in these countries. Given the large variety of cheeses – 1 400 varieties, according to some estimates (Fox and McSweeney, 2004) – and considerable body of literature available, it is beyond the scope of this chapter to discuss cheese in detail.

Cheese from whole cow milk (0901): *Curd of milk that has been coagulated and separated from whey. May include some skimmed milk.*

Cheese from skimmed cow milk (0904): *May include some whole milk.*

Processed cheese (0907); Cheese of goat milk (1021); Cheese of sheep milk (0984); Whey cheese (0905): no definitions given.

Whey cheese is not a "real" cheese according to the definition above for cheese, as it is produced from milk whey and not curd. Ricotta is an example of whey cheese (see Table 3.10 for nutrient composition).

The *CODEX general standard for cheese* (FAO and WHO, 2010g) provides the following definitions and guidelines:

> *"Cheese is the ripened or unripened soft, semi-hard, hard, or extra-hard product, which may be coated, and in which the whey protein/casein ratio does not exceed that of milk, obtained by:*
> *(a) coagulating wholly or partly the protein of milk, skimmed milk, partly skimmed milk, cream, whey cream or buttermilk, or any combination of these materials, through the action of rennet or other suitable coagulating agents, and by partially draining the whey resulting from the coagulation, while*

TABLE 3.8
Cheese production (tonnes), 2009

	Production (t)
World	19 358 614
Africa	907 838
Americas	6 380 884
Asia	1 418 284
Europe	10 001 590
Oceania	650 016
Least Developed Countries	300 586
Low Income Food Deficit Countries	1 488 557

Source: FAOSTAT.

respecting the principle that cheese-making results in a concentration of milk protein (in particular, the casein portion), and that consequently, the protein content of the cheese will be distinctly higher than the protein level of the blend of the above milk materials from which the cheese was made; and/or
(b) processing techniques involving coagulation of the protein of milk and/or products obtained from milk which give an end-product with similar physical, chemical and organoleptic characteristics as the product defined under (a).”

The main step in cheese-making, the coagulation of the casein component, is achieved using one of the following methods, or a combination of these methods: a) limited proteolysis using enzymes; b) acidification by adding acids or a starter culture; and c) acidification combined with heating to about 90 °C (Fox and McSweeney, 2004; Henning *et al*., 2006). The majority of cheeses are produced by enzymatic (rennet) coagulation; rennet from the stomachs of young calves, kids, lambs and buffalo was traditionally used (Fox and McSweeney, 2004).

The coagulated milk, the curd, can be separated from the whey in several ways. For Camembert (defined in CODEX as a “soft surface ripened, primarily mould ripened cheese”), the curd is ladled into moulds and kept overnight while the whey is slowly drained off; the moulds are turned regularly to allow the whey to drain. In some other cheeses, the curd is cut into cubes while being heated, causing it to float in the whey. The whey is drained off, while the curd is subjected to syneresis (dehydration); this involves cutting the coagulum, cooking, stirring, pressing, salting and other operations that promote gel syneresis (Fox and McSweeney, 2004). The final stages are shaping (moulding and pressing) and salting, which contributes to the dehydration process (about 2 kg of water is lost per kg of NaCl taken up) (Fox and McSweeney, 2004).

Cheeses are also classified according to the post-coagulation operations they have undergone (Table 3.9). The majority of rennet-coagulated cheeses are subjected to ripening. According to the CODEX general standard for cheese (FAO and WHO, 2010g):

*“**Ripened cheese** is cheese which is not ready for consumption shortly after manufacture but which must be held for such time, at such temperature, and*

TABLE 3.9
CODEX designation of cheese according to firmness and ripening characteristics

According to firmness		According to principal ripening
MFFB%*	Designation	
<51	Extra hard	Ripened
49–56	Hard	Mould ripened
54–69	Firm/semi-hard	Unripened/fresh
>67	Soft	In brine

* MFFB equals percentage moisture on a fat-free basis, i.e.
[Weight of moisture in the cheese/(Total weight of cheese – Weight of fat in the cheese)] × 100

under such other conditions as will result in the necessary biochemical and physical changes characterising the cheese in question.
***Mould ripened cheese** is a ripened cheese in which the ripening has been accomplished primarily by the development of characteristic mould growth throughout the interior and/or on the surface of the cheese.*
***Unripened cheese** including fresh cheese is cheese which is ready for consumption shortly after manufacture".*

CODEX provides the following example: "The designation of a cheese with moisture on a fat-free basis of 57 percent which is ripened in a manner similar in which Danablu (Danish blue cheese) is ripened would be: 'Mould ripened firm cheese or firm mould ripened cheese.'"

Other examples from CODEX:

- Unripened (fresh) cheese: Mozzarella (made by "pasta filata" processing, which consists of heating curd of a suitable pH value and then kneading and stretching the curd until it is smooth and free from lumps. Still warm, the curd is cut and moulded, then firmed by cooling)
- Soft, rind less, unripened cheese: Cottage cheese
- Soft surface ripened, primarily mould ripened cheese: Camembert, Coulommiers
- Soft surface ripened, primarily white mould ripened cheese: Brie
- Ripened firm/semi-hard cheese: Saint-Paulin, Edam, Gouda, Provolone, Tilsiter, Danbo, Havarti
- Ripened hard cheese: Samsø, Emmental, Cheddar.

Blue cheeses are characterized by the growth of the mould *Penicillium roqueforti,* which gives them their typical appearance and flavour (Cantor *et al*., 2004). Most sheep milk cheeses are either uncooked blue-veined hard cheeses (e.g. Roquefort) or pressed cheeses (e.g. Ossau-Iraty), while goat milk cheeses are generally soft ripened cheeses or soft lactic cheeses (e.g. Rocamadour). For a review, see Raynal-Ljutovac *et al*. (2008).

Regarding the declaration of milk fat content in cheese, CODEX states the following:

"The milkfat content shall be declared in a manner found acceptable in the country of sale to the final consumer, either (i) as a percentage by mass, (ii) as a percentage of fat in dry matter, or (iii) in grams per serving as quantified in the label provided that the number of servings is stated.
Additionally, the following terms may be used:
***High fat** (if the content of FDM [fat in dry matter] is above or equal to 60%)*
***Full fat** (if the content of FDM is above or equal to 45% and less than 60%)*
***Medium fat** (if the content of FDM is above or equal to 25% and less than 45%)*
***Partially skimmed** (if the content of FDM is above or equal to 10% and less than 25%)*
***Skim** (if the content of FDM is less than 10%)"*

Nutrient profile of cheese and the impact of cheese-making on nutrient profiles

Cheese contains high levels of essential nutrients relative to its energy content, although the nutritional profile varies with the type of milk, the type of starter

culture, the method of manufacture and ripening conditions (Henning *et al*., 2006). Table 3.10 gives the nutrient composition of a few representative cheeses.

About 10 litres of milk are required to produce 1 kg of cheese, and during the process the water-soluble material (whey proteins and water-soluble vitamins) are separated from the casein, fat and salts (Wigertz, Svensson and Jägerstad, 1997). The casein remains in the curd, but caseins are low in sulphur-containing amino acids and the nutritional value of cheese protein is slightly lower than that of total milk protein (Henning *et al.,* 2006). Not more than 75 percent of the total protein in milk is recovered in rennet-coagulated cheeses (Fox and McSweeney, 2004). Some whey can remain trapped within the curd, contributing to increased supplies of essential amino acids such as cysteine, isoleucine, leucine, lysine, threonine and tryptophan (Raynal-Ljutovac *et al.,* 2008). Newer methods in cheese-making attempt to increase the nutrient value of cheese by including the whey proteins in the curd. Methods used to achieve this include heat-treatment to denature the whey proteins (causing them to form protein aggregates with κ-casein), adding the whey proteins at a later stage of the manufacturing process and ultrafiltration, especially in the case of semi-hard or soft cheeses, e.g. feta, a soft, white cheese ripened in brine, manufactured from sheep milk, or a mixture of sheep and goat milk (Manolopoulou *et al*., 2003; Guyomarc'h, 2006).

Most milk used in cheese-making is pasteurized, usually immediately before use (Fox and McSweeney, 2004). During pasteurization, whey proteins are denatured (as discussed in Section 3.3.2) and the resulting β-lactoglobulin–κ casein entraps denatured whey proteins, which may lead to some minor differences in amino acid profiles between lactic cheese and soft cheese (Henry *et al*., 2002 cited in Raynal-Ljutovac *et al.,* 2008).

A progressive breakdown of casein during ripening is reported to increase its digestibility (Henning *et al.*, 2006). Moreover, proteolysis induced by fermentation and ripening increases amounts of bioactive peptides and free amino acids present in the cheese. The free amino acids present in goat cheese are glutamic acid, leucine and lysine (Bordet, 1990 and Casalta *et al*., 2001, cited in Raynal-Ljutovac *et al.,* 2008).

The loss in vitamins induced by pasteurization was discussed in Section 3.3.2. Water-soluble vitamins are lost in the whey; high folate content is reported in whey products (Wigertz, Svensson and Jägerstad, 1997). These authors found little 5-methyltetrahydrofolate (5-CH_3THF, the major form of folate in milk) in hard cheeses (115–181 µg/kg after deconjugation), but much more in cottage cheese (average 215 µg/kg), which has a considerable amount of whey remaining with the cheese plus has pasteurized cream added to the final product (Wigertz, Svensson and Jägerstad, 1997). Whey cheeses contained 344–506 µg/kg 5-CH_3THF after deconjugation. According to these authors, folate concentrations in cheese are likely to be low, in part because of losses in the whey. However, they concede that, depending on the strains of organisms used and the manufacturing procedure, folate may actually be synthesized, as reported by other authors. A high content of both vitamin B_6 and folate was reported in ripened goat milk cheeses (Raynal-Ljutovac *et al*., 2008), which the authors say suggests synthesis by micro-organisms. They say that these results corroborate the results of Lucas *et al*. (2006a), who found a high folate content in Rocamadour (1 010 µg/kg) compared with pressed cow milk cheeses, and Favier and Dorsainvil (1987), who found a high folate content especially in the rind of soft lactic goat milk cheeses. According to Raynal-Ljutovac *et al*. (2008), the high

TABLE 3.10
Main nutrient composition in common cheeses (g/100 g)

		Water (g)	Energy (kcal)	Energy (kJ)	Protein (g)	Total fat (g)	Lactose (g)
Blue cheese*	average	43.5	356	1 486	21.0	29.9	0.4
	range	38.0–50.8	324–410	1 356–1 698	19.1–23.7	27.1–35.0	0.1–1.0
Brie	average	48.8	331	1 381	20.0	27.9	0.3
	range	48.42–49.3	319–343	1 336–1 422	19.3–20.8	26.9–29.1	0.1–0.45
Camembert	average	51.9	297	1 241	20.9	23.7	0.2
	range	50.5–54.4	286–312	1 200–1 304	19.6–22.6	21.7–26.2	0.1–0.5
Cheddar	average	36.5	406	1 696	25.1	33.7	0.3
	range	34.0–38.5	381–427	1 594–1 786	24.2–26.2	31.0–36.6	0.1–0.5
Cottage cheese	average	79.3	99	415	12.4	4.4	2.2
	range	78.6–79.8	94–103	393–433	11.1–13.7	3.5–5.4	1.0–3.1
Gouda	average	46.1	338	1 409	23.0	26.6	2.2
	range	41.5–50.8	320–356	1 329–1 489	21.1–24.9	25.8–27.4	2.2–2.2
Edam	average	41.5	353	1 472	26.6	27.1	0.8
	range	39.0–43.8	341–360	1 416–1 507	25.0–28.1	26.0–27.8	0.1–1.4
Feta	average	56.1	254	1 059	16.1	20.2	1.8
	range	54.9–57.1	249–264	1 037–1 105	14.2–19.4	19.2–21.3	0.5–4.1
Mozzarella[1]	average	53.9	275	1 148	22.1	20.3	0.5
	range	49.7–58.8	253–300	1 058–1 255	16.7–28.9	17.7–24.4	0.1–1.0
Parmesan	average	27.3	402	1 679	37.6	27.2	0.5
	range	16.0–36.4	356–444	1 488–1 860	33.6–44.9	24.1–29.7	0.1–0.9
Ricotta (whey cheese)[2]	average	73.4	155	651	9.7	11.6	2.5
	range	71.7–75.7	144–174	603–728	8.8–11.3	10.9–13.0	0.3–4.2
Pecorino (sheep cheese)	average	34.0	392	1 640	25.8	32.0	0.2
Goat cheese, hard	average	29.0	452	1 891	30.5	35.6	2.2
Goat cheese, soft	average	55.8	294	1 225	19.8	23.4	0.9
	range	60.8–50.8	268–320	1 121–1 329	18.5–21.1	21.1–25.8	0.9–0.9

The data were obtained (where available) from the following databases: USDA, Food Standards Agency/McCance and Widdowson, Danish Food Composition Databank, New Zealand food composition tables, Italian Food Composition database. The number of data points varied.

* Blue cheese includes Roquefort (sheep milk), Stilton, Gorgonzola and Danish Blue (Danablu).

[1] Includes milk from cow and buffalo.

[2] Includes milk from cow and sheep.

folate content of these cheeses are of nutritional importance given the lack of this compound in raw goat milk. B vitamins may either be produced by yeasts (mainly *Saccharomyces* species) or lactic acid bacteria, the amount depending on bacterial strains (Raynal-Ljutovac *et al.,* 2008) and manufacturing procedures (Wigertz, Svensson and Jägerstad, 1997). For instance, in yoghurts, *Streptococcus thermophilus* and *Lactobacillus acidophilus* produce folic acid whereas *Lactobacillus bulgaricus* consume it (Forssen *et al*., 2000, cited in Raynal-Ljutovac *et al.,* 2008). The authors note that "as the type of ripening strains and ripening parameters (e.g. temperature/time) may differ between each class of products, it may induce variations in B vitamin contents and especially high folate content for raw milk ripened lactic cheeses". Vitamin data are scarce for sheep milk cheeses (Raynal-Ljutovac *et al.,* 2008).

Whey contains up to 94 percent of the lactose, much of which is lost in cheese-making. The remaining lactose is partially transformed into L-lactate or D-lactate (Trujilllo *et al.*, 1999, cited in Raynal-Ljutovac *et al.,* 2008), or into glucose and galactose on cheese-making. These residual carbohydrates found in fresh cheeses disappear with increasing ripening time (Raynal-Ljutovac *et al.,* 2008). Lactose content in cheese is generally less than 1 g/100 g, with a few exceptions (Table 3.10). Ricotta has a high lactose content as it is made from milk whey.

The curd contains almost 95 percent of the fat, and during cheese-making the fat is concentrated between 6- and 12-fold, depending on cheese variety (Fox and McSweeney, 2004). A study on goat and sheep milks and cheeses obtained from French dairies or farms found no significant differences between the FA profile of the milks and those of the full cream cheeses Roquefort (an uncooked blue-veined hard cheese made from sheep milk) and Ossau-Iraty (pressed cheese made from sheep milk), which indicated that the FA profiles of these cheeses were directly related to those of the parent milks (Raynal-Ljutovac *et al*., 2008). Given this relationship between milk and FA profiles, goat and sheep cheeses contain higher levels of short- and medium-chain FAs than do cow milk cheeses (Raynal-Ljutovac *et al*., 2008).

The average CLA content in cheese is reported to be 0.5–1.7 g/100 g of total FAs (Henning *et al*., 2006). The CLA content in sheep cheeses has been reported to be higher than that of cow or goat milk cheeses (Prandini, Sigolo and Piva, 2011), with average values of 0.6, 0.7 and 1.0 g of CLA/100 g total FA in cow, goat and sheep cheeses, respectively. A review on the influence of processing on CLA content in dairy products concluded that no changes in the CLA content occurs during manufacturing or ripening of cheese (Bisig *et al*., 2007). A similar conclusion was reached by Prandini, Sigolo and Piva (2011). Although the content of nutritionally interesting FAs such as CLA can be increased by lipid supplementation of the goat diet, this may be accompanied by a change in cheese flavour (Chilliard and Ferlay, 2004, Chilliard *et al.*, 2005 and Chilliard *et al*., 2006a, cited in Raynal-Ljutovac *et al.*, 2008).

A similar result was reported for the *trans*-FA content in Emmental cheeses made from milk produced by cows on three different diets (Briard-Bion *et al*., 2008). The *trans*-FA content varied from 4–10 g/100 g total fat depending on the diet, and was not significantly different ($P < 0.05$) from those in the parent milks. Therefore, neither the thermal and mechanical treatments applied during processing nor the enzymatic and chemical reactions occurring during ripening had any effect on the *trans*-FA content.

Contents of other fat soluble compounds such as β-carotene (for cow milk cheese), xanthophylls and vitamin E have also been shown to depend on the original milk composition, rather than on cheese processing (Lucas *et al*., 2006a, 2006b, cited in Raynal-Ljutovac *et al.,* 2008). However, vitamin A content was partially influenced by both the original milk composition and the cheese-making process (Lucas *et al*., 2005, cited in Raynal-Ljutovac *et al.,* 2008).

Mineral contents vary with cheese type. The strong decrease in pH occurring early in the production process of some types of cheeses (during coagulation) make calcium, phosphorus and zinc (mainly bound to caseins) soluble and these are therefore lost with the whey during draining (Raynal-Ljutovac *et al.,* 2008). Potassium and magnesium, which are essentially soluble, also decreased as dry matter increased through pressing or aging (Raynal-Ljutovac *et al.,* 2008). An acid-coagulated fresh cheese like cottage cheese contains 83 mg of calcium/100 g, compared with 720 mg/100 g in a hard cheese like cheddar (USDA, 2009). The calcium in cottage cheese is mainly from the whey that remains with the curd after processing. All lactic goat cheeses were found to have similar calcium contents, showing an overall similar demineralization (Raynal-Ljutovac *et al.,* 2008). Magnesium concentrations in fresh lactic goat cheeses were reported to be similar to that in goat milk, while Camembert-type cheeses were reported to contain higher quantities of magnesium (Raynal-Ljutovac *et al*., 2008). Selenium concentration was reported to depend on its availability in soil for assimilation by grass and its further recovery in milk and cheeses; selenium is then concentrated by the drying (ripening) effect (Pizzoferrato, 2002, cited in Raynal-Ljutovac *et al.*, 2008).

Studies on the bioavailability of minerals from cheese have reported few differences between milk and cheese. Furthermore, few differences in the absorption coefficient of calcium (in humans) between milk and other dairy products such as hard cheese (Cheddar) or fresh cheeses have been reported (Guéguen and Pointillart, 2000, cited in Raynal-Ljutovac *et al*., 2008).

3.3.5 Butter and ghee

Butter of cow milk (0886): *Emulsion of milk fat and water that is obtained by churning cream. Trade data cover butter from the milk of any animal.*

Butter of buffalo milk (0952): No definition.

Butter of goat milk (1022): No definition.

Butter and ghee of sheep milk (0983): No definition.

Ghee from cow milk (0887): *Butter from which the water has been removed. Very common in hot countries. Includes also anhydrous butterfat or butter oil.*

The heat treatment involved in the manufacturing process for ghee and the very low moisture content of the final product prevents the growth of most microorganisms in ghee. Therefore, ghee has a shelf-life of 6–8 months, or even up to 2 years according to some reports. Ghee has been produced in India since 1500 BC (Achaya, 1997, cited in Sserunjogi, Abrahamsen and Narvhus, 1998). Ghee is widely used in the Indian subcontinent as a cooking and frying medium. Nearly 40 percent

of the world's butter/ghee is produced in India, with a total of 3.8 million tonnes in 2009 (FAOSTAT). While Indian ghee is made from cow or buffalo milk, or a mixture of these milks, Middle Eastern ghee is mainly from goat, sheep or camel milks and is known by the names of *maslee*, *roghan* and *samn* (Sserunjogi, Abrahamsen and Narvhus, 1998). Other indigenous products related to ghee include *samna* (Egypt), *meshho* (an Assyrian non-perishable milk fat), Ethiopian indigenous ghee, *samin* (Sudan) and *samuli* (Uganda).

Nutrient profile of butter and ghee

Approximately 81 percent of butter and 99.5 percent of ghee consists of fat (see Table 3.7). According to the FAOSTAT Food Balance Sheets, butter and ghee provide a global average of 28 kcal of energy/capita per day and 3.2 g of /capita per day, ranging from 67–90 kcal of energy/capita per day and 8–10 g of fat/capita per day in Europe and Oceania to only 7 kcal of energy/capita per day and 1 g of fat/capita per day in Africa.

Ghee contains large amounts of fat-soluble vitamins: 100 g of ghee is reported to have a vitamin A content of 600 µg RE (INFS/WFP, 1988), 8 µg of vitamin D and 2.8 mg of vitamin E (Sserunjogi, Abrahamsen and Narvhus, 1998). Based on the *CODEX guide to food labelling* (FAO and WHO, 2001), ghee can be labelled as high in both vitamin A and vitamin D (CODEX does not have a Nutrient Reference Value for vitamin E).

The FA profiles are generally similar in ghee made from cow and sheep milk (Al-Khalifah and Al-Kahtani, 1993). Although the FA content of the original milks is not known, values for SFA content suggest that the FA profile is similar to that of the parent milks. Palmitic (C16:0) and oleic (C18:1) acids are the main FAs in both cow and sheep milk ghee (Al-Khalifah and Al-Kahtani, 1993).

The CLA content is reported to be higher in ghee than in the parent milk fat (Aneja and Murthi, 1991, cited in Sserunjogi, Abrahamsen and Narvhus, 1998; Bisig *et al.*, 2007) and can be increased by up to fivefold by increasing the temperature of clarification from 110 °C to 120 °C. No such changes were reported in the manufacture of butter (Bisig *et al.*, 2007). Butter and ghee are the richest source of CLA (Sserunjogi, Abrahamsen and Narvhus, 1998). Ghee is also reported to contain essential FAs (Rangappa and Achaya, 1974, and Chand *et al.*, 1986, cited in Kumar *et al.*, 2010). The cholesterol content is reported to range from 200–400 mg/100 g in ghee from cow, sheep and buffalo milks (Al-Khalifah and Al-Kahtani, 1993; Kumar *et al.*, 2010), compared with about 10 mg/100 g in milk.

3.3.6 Cream

Cream, fresh (0885): *That portion of milk which is rich in milk fat and is separated by skimming or centrifuging.*

The *CODEX standard for cream and prepared creams* (FAO and WHO, 2010h) defines cream, reconstituted cream, recombined cream and prepared creams (prepackaged liquid cream, whipping cream, cream packed under pressure, whipped cream, fermented cream and acidified cream) as follows:

> *"**Cream** is the fluid milk product comparatively rich in fat, in the form of an emulsion of fat-in-skimmed milk, obtained by physical separation from milk.*

Reconstituted cream *is cream obtained by reconstituting milk products with or without the addition of potable water and with the same end product characteristics as the product described above.*
Recombined cream *is cream obtained by recombining milk products with or without the addition of potable water and with the same end product characteristics as the product described in (cream).*
Prepared creams *are the milk products obtained by subjecting cream, reconstituted cream and/or recombined cream to suitable treatments and processes to obtain the characteristic properties as specified below:*
Pre-packaged liquid cream *is the fluid milk product obtained by preparing and packaging cream, reconstituted cream and/or recombined cream for direct consumption and/or for direct use as such.*
Whipping cream *is the fluid cream, reconstituted cream and/or recombined cream that is intended for whipping. When cream is intended for use by the final consumer the cream should have been prepared in a way that facilitates the whipping process.*
Cream packed under pressure *is the fluid cream, reconstituted cream and/or recombined cream that is packed with a propellant gas in a pressure-propulsion container and which becomes Whipped Cream when removed from that container.*
Whipped cream *is the fluid cream, reconstituted cream and/or recombined cream into which air or inert gas has been incorporated without reversing the fat-in-skimmed milk emulsion.*
Fermented cream *is the milk product obtained by fermentation of cream, reconstituted cream or recombined cream, by the action of suitable micro-organisms, that results in reduction of pH with or without coagulation. Where the content of (a) specific micro-organism(s) is (are) indicated, directly or indirectly, in the labelling or otherwise indicated by content claims in connection with sale, these shall be present, viable, active and abundant in the product to the date of minimum durability. If the product is heat-treated after fermentation the requirement for viable micro-organisms does not apply.*
Acidified cream *is the milk product obtained by acidifying cream, reconstituted cream and/or recombined cream by the action of acids and/or acidity regulators to achieve a reduction of pH with or without coagulation."*

According to the FAOSTAT Food Balance Sheets, globally cream provides an average 2 kcal of energy/capita per day and 0.2 g of fat/capita per day, ranging from 17 kcal of energy/capita per day and 1.7 g of fat/capita per day in Europe to less than 2 kcal of energy/capita per day and less than 0.2 g of fat/capita per day in the rest of the world. Values for the main nutrients in cream are given in Table 3.7.

3.3.7 Whey products

Whey, fresh (0903): *The liquid part of the milk that remains after the separation of curd in cheese making. Its main food use is in the preparation of whey cheese, whey drinks and fermented whey drinks. The main industrial uses are in the manufacture of lactose, whey paste and dried whey.*

Whey is rich in whey proteins, water-soluble vitamins and lactose. Two types of whey exist: acid whey, obtained during the production of acid-coagulated cheeses such as cottage cheese, and sweet whey, from the manufacture of rennet-coagulated cheese. Acid whey contains twice as much calcium as sweet whey.

Whey, condensed (0890): *Whey paste.*

Whey, dry (0900): *Used in both food and animal feed.*

The *CODEX standard for whey powders* (FAO and WHO, 2010i), defines the composition of sweet whey as follows:

- lactose: reference content of 61 percent
- milk protein: minimum content 10 percent
- milk fat: reference content 2 percent
- water: maximum content 5 percent
- ash: maximum content 9.5 percent.

The composition of acid whey is defined as follows:

- lactose: reference content of 61 percent
- milk protein: minimum content 7 percent
- milk fat: reference content 2 percent
- water: maximum content 4.5 percent
- ash: maximum content 15 percent.

Whey cheese (0905): No definition given.

The *CODEX standard for whey cheeses* (FAO and WHO, 2010j) states that:

"Whey Cheeses are solid, semi-solid, or soft products which are principally obtained through either of the following processes:
(1) the concentration of whey and the moulding of the concentrated product;
(2) the coagulation of whey by heat with or without the addition of acid.
In each case, the whey may be pre-concentrated prior to the further concentration of whey or coagulation of the whey proteins. The process may also include the addition of milk, cream, or other raw materials of milk origin before or after concentration or coagulation. The ratio of whey protein to casein in the product obtained through the coagulation of whey shall be distinctly higher than that of milk.
The product obtained through the coagulation of whey may either be ripened or unripened."

It also gives the following standards for fat in whey cheeses (dry-matter basis):

- creamed whey: cheese minimum 33 percent
- whey cheese: minimum 10 percent and less than 33 percent
- skimmed-whey cheese: less than 10 percent.

Lactose (0173): *Also known as milk sugar. Produced commercially from whey.*

Other products produced from whey include whey protein concentrate and whey protein isolate.

3.3.8 Casein

Casein (0917): *The main protein constituent of milk. Casein is obtained from skimmed milk by precipitation (curdling) with acids or rennet.*

The *CODEX standard for edible casein products* (FAO and WHO, 2010k) specifies acceptable composition of rennet casein, acid casein and caseinates. Caseins are low in sulphur amino acids, which limits their biological value (Fox and McSweeney, 1998).

3.3.9 Milk products from milk from underutilized species

With the exception of some fermented milks and milk powder made from mare milk, most of the milk products presented in the preceding sections are made from milk from common dairy animals (cow, sheep, goat and buffalo). Data on milk products from milk from underutilized species are less common in literature, and are outlined below.

Reindeer milk

Reindeer milk is important in the summer diet of herders, dried in curd form, or made into cheese, butter and sour cream. The fat content increases significantly as lactation progresses (see Section 3.2.3). The milk from the first part of the lactation is drunk, milk from mid-lactation is used for cheese-making and milk from late lactation is churned to produce butter (Holand, Gjøstein and Nieminen, 2006).

Yak milk

Mongolian people use yak milk to produce a range of food products, including the fermented milk products kurut (Section 3.3.3) and koumiss, yoghurt, fresh cheese and two types of butter, one of which is used for daily consumption. The other, consisting of protein and fat, is called "white butter" and is used as food during the winter in mixtures with sugar and other products (Indra and Magash, 2002). Yak cheese (a hard, Swiss-style Gruyére cheese) is produced in Nepal, Mongolia, Bhutan, India and Pakistan (FAO, 2003), with the yak cheese industry being of significant importance for rural income and employment in Nepal.

Camel milk

Although most camel milk is consumed raw or in the form of fermented milk, commercial farms supply fresh pasteurized milk in Saudi Arabia (Mehaia *et al.*, 1995). Bactrian camel milk is used for making cheese, butter and yoghurt in Mongolia (Jirimutu *et al.*, 2010). Studies on dromedary camel milk report that camel milk is less favourable for cheese-making than cow, sheep and goat milk because it does not produce a curd but rather produces flakes that lack firmness (Mehaia, 1997; Bornaz *et al.*, 2009). Dromedary camel milk has been shown to be suitable for butter-making, despite the belief among many camel-rearing societies that butter cannot be made from camel milk (Streiff and Bachmann, 1989). The authors note that camel cream has different churning properties to cream from cow milk and attribute these differences to the high melting point of camel fat and small size of camel milk fat globules. Bedouin in the Negev desert make ice cream from camel milk (Guliye, Yagil and DeB Hovell, 2000), which is sold to tourists.

Other milks

No milk products have been reported from llama, alpaca, mithun or moose milks.

3.4 KEY MESSAGES

Cow milk is energy-dense and provides high-quality protein. It can make a significant contribution to meeting the required nutrient intakes of calcium, magnesium, selenium, riboflavin, vitamin B_{12} and pantothenic acid. However, cow milk does not contain sufficient iron and folate to meet requirements, and animal milks are not recommended for infants younger than 12 months. The total fat in cow milk generally ranges between 3 and 4 g/100 g, with SFAs comprising 65–75 g/100 g of total FA. Values for *trans*-FA lower than 10 g/100 g total FA are reported, varying with feed.

Milks from other dairy species are also generally a source of protein and are either high in or a source of calcium. Sheep, mare and donkey milks can be considered sources of vitamin C. Sheep, goat, buffalo and Bactrian camel milks are high in or a source of riboflavin. Buffalo milk is high in vitamin B_6, while buffalo, Bactrian camel and goat milks can be sources of vitamin A. Bactrian camel milk is high in vitamin D.

There are large interspecies differences in nutrient composition: species averages for total fat range from 0.7 to 16.1 g/100 g, protein ranges from 1.6 to 10.5 g/100 g and lactose ranges from 2.6 to 6.6 g/100 g. The two extremities are cervid (e.g. reindeer and moose) milks (high in protein and fat, low in lactose) and equine milks (low in protein and fat, high in lactose).

Milk FA composition also varies with species. While most milks contain large amounts of SFA (>65 g/100 g total FA), horse, donkey and Bactrian camel milks have been reported to contain less (40–55 g/100 g total FA). The individual SFA pattern also varies with species, e.g. goat and sheep milks are rich in short- and medium-chain FAs of 4–10 carbon atoms. Equine milks have a higher polyunsaturated FA content than other milks (more than 20 g/100 g total FA in equine milks compared with about 6 g/100 g total FA in cow milk).

There are also interspecies variations in milk proteins. The casein:whey-protein ratio in most milks is approximately 80:20, although equine milks resemble human milk in their relatively low content of caseins (40–45 percent). The individual proteins also vary, making camel milks and equine milks possibly more suitable for people who are allergic to cow milk.

Heat treatment is associated with changes in nutrients. Losses in vitamin C, folate, thiamine, pyridoxine and vitamin B_{12} occur, the percentage loss generally depending on severity of heat treatment, in the order sterilization > UHT treatment > pasteurization.

In fermented milks the lactose content is lower, and both lactose and milk proteins are more easily digestible than in the original milk. The folate content in yoghurt, dahi and fermented milks can sometimes be higher than in the original milk.

During traditional cheese-making, the milk whey, which contains whey proteins, water-soluble vitamins and much of the lactose, is removed, while the curd contains casein, fat and salts. Progressive breakdown of casein during ripening may increase the digestibility of cheese, and beneficial bioactive peptides and free amino acids may be formed during fermentation and ripening processes. Mineral contents vary with cheese type.

3.5 ISSUES AND CHALLENGES

Milk composition is affected by various factors including stage of lactation, breed differences, number of calvings (parity), seasonal variations, age and health of animal, feed and management effects, which makes it difficult to compare compositional data (in absolute terms) between studies. In order to permit such meta-analyses published studies should include information on the above factors, analytical methods used and, where possible, have a control group for comparison.

Animal feed strategies and genetic improvement methods are likely to be increasingly used to modify milk composition, for example to tailor the milk fat composition to meet specific needs. Further research on the nutritional and food safety implications is needed.

The importance of biodiversity in strengthening food security and nutrition is increasingly apparent. More data are needed at breed level and on underutilized species to develop the knowledge base on livestock biodiversity to help to maintain local species and breeds that may otherwise become extinct, and to ensure that breeders and livestock rearers can identify breeds and species that meet their specific needs.

Recent estimates have shown that the dairy sector accounts for 4 percent of total anthropogenic anthropogenic greenhouse gas (GHG) emissions, with methane accounting for over half of total emissions (FAO, 2010). Monogastric animals such as horses and donkeys emit less methane as part of their digestive processes, and thus offer possibilities of reducing GHG emissions while maintaining milk production. Further studies on the production and composition of their milk may be important for future decision-making for sustainable diets.

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The authors declare that no financial or other conflict of interest exists in relation to the content of the chapter.

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Chapter 4

Milk and dairy products as part of the diet

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ABSTRACT

This chapter reviews the health aspects of cow milk and dairy products in the human diet. The first section presents milk as a source of macro- and micronutrients, and nutrient composition of milk with respect to nutritional requirements is discussed. The section on dairy in growth and development considers effects on children's linear growth; milk's role in treatment of undernutrition; milk in the diets of well-nourished children; and secular trend of increasing adult height. Possible mechanisms for growth-stimulating effects of milk are presented. The section on bone health looks at dietary factors that affect bone health, with emphasis on calcium, vitamin D and protein. Studies looking at the effects of milk/calcium on bone mineral density are presented, followed by findings on the effects of dairy on osteoporosis, fracture and rickets. Anticariogenic properties of milk and dairy products are also considered. The relationship between dairy intake, weight gain and obesity development is considered, which includes the association between dairy intake and weight status, and dairy as part of a weight loss strategy. The role of dairy in metabolic syndrome and type 2 diabetes is also covered. In the section on cardiovascular disease (CVD) and dairy, we consider the effects of dietary fat on CVD, and look at studies that support reducing animal products and the argument for low-fat versus high-fat dairy products. Results from recent review studies on milk/dairy consumption with respect to CVD are presented. Other dairy products and risk of CVD are also briefly visited. The role of dairy products and calcium at different cancer sites are discussed, drawing on the findings of the World Cancer Research Fund (WCRF)/American Institute for Cancer Research (AICR). Milk hypersensitivity, attributed to either lactose malabsorption or cow milk allergy is discussed. Finally, the role of dairy in the dietary recommendations of 42 countries is discussed, and the wide variation in guidelines regarding the type of dairy (e.g. low- vs. high-fat, and dairy products such as milk, butter, etc.) and amount and frequency of consumption noted.

Keywords: Milk, dairy, bone, dental caries, obesity, metabolic syndrome, cardiovascular disease, cancer, milk hypersensitivity

4.1 INTRODUCTION

Milk and dairy foods are nutrient-dense foods supplying energy and significant amounts of protein and micronutrients. The inclusion of dairy products adds diversity to plant-based diets. However, the role of milk and dairy products in human nutrition has been increasingly debated in recent years, both in the scientific literature and in popular science literature.

The primary role of milk is to nourish the infants of a species. The consumption of animal milk is a by-product of animal domestication, which occurred about 10 000 years ago. For early humans, the advantages of milk consumption and its effects on growth and bone health were likely to have been of considerable importance while its effects on chronic diseases later in life had limited relevance to reproduction and survival. In contrast, for contemporary human populations, while childhood growth and bone strength are important for health, it is the effects of milk and dairy consumption on individual well-being and on chronic diseases and their associated economic costs that are of greater relevance (Elwood *et al*., 2008).

Milk is a complex food containing numerous nutrients. Most of the constituents in milk do not work in isolation, but rather interact with other constituents. Often, they are involved in more than one biological process, sometimes with conflicting health effects, depending on the process in question. One such example is milk fat. The traditional diet-heart paradigm, developed in the 1960s and 1970s, held that consumption of fat, and saturated fat in particular, raised total cholesterol and low-density lipoprotein (LDL) cholesterol levels, leading to coronary heart disease (CHD) (Mozaffarian, 2011). Some of the evidence that is often cited to support reduced consumption of animal fat will be briefly discussed in Section 4.8. Currently, many national and international bodies recommend consumption of lower-fat dairy foods. However, the scientific rationale behind this recommendation is still debated. As one author says, "Due to the small rise in blood cholesterol with milk drinking, the debate on milk has never achieved a reasonable balance on the evaluation of risks and benefits" (Elwood *et al*., 2010). It is also important to remember that dietary fats, in addition to being a concentrated energy source, serve as an important delivery medium for fat-soluble vitamins and contain various fatty acids (e.g. conjugated linoleic acid [CLA]) and bioactive factors beneficial to health (e.g. triacylglycerols and phospholipids) (German and Dillard, 2006; Kris-Etherton, Fleming and Harris, 2010). Similarly, to consider even saturated fatty acids (SFAs) as one uniform group of fats may be an over-simplification (FAO and WHO, 2010; Feinman, 2010), since individual fatty acids (FAs) have specific functions depending on their chain length.

This chapter summarizes the available evidence on the relationship between dairy consumption and health. The majority of published papers (including much of the epidemiological evidence) relate to milk; therefore, this chapter deals primarily with milk, with other dairy products being covered in less detail. With few exceptions, we comment on the findings of the most recent review papers, which included both systematic reviews and narrative reviews, rather than on individual studies. As it was not possible to conduct a systematic review of the literature because of the broad scope of material covered in this chapter, where appropriate we have referred

to systematic reviews/recommendations provided by other learned bodies, such as the FAO/WHO 2010 expert consultation on fats and fatty acids (FAO and WHO, 2010); the FAO/WHO expert consultation on vitamin and mineral requirements (FAO and WHO, 2002); WHO/FAO expert consultation on diet, nutrition and the prevention of chronic diseases (WHO and FAO, 2003); the World Cancer Research Fund/American Institute for Cancer Research report on food, nutrition, physical activity and the prevention of cancer (WCRF and AICR, 2007); the European Food Safety Authority (EFSA) Panel on Dietetic Products, Nutrition, and Allergies; the United States National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults; and the World Allergy Organization Diagnosis and Rationale for Action against Cow's Milk Allergy (DRACMA) guidelines (Fiocchi *et al.*, 2010). This is particularly so for areas such as Cardiovascular disease (Section 4.8) and Cancer (Section 4.9), where we were compelled to depend on review studies rather than considering individual studies because of the large amount of published literature on these topics.

4.1.1 Limitations of studies reviewed

In theory, only randomized control intervention studies can provide definitive answers to questions about risks and benefits of milk consumption. For such studies to show causation and a population health impact ideally they need to cover the life span of the study subjects and involve large numbers of people. Such studies are very costly and difficult to carry out for both ethical and methodological reasons (Alvarez-León, Román-Viñas and Serra-Majem, 2006; Elwood *et al.,* 2010; Givens, 2010). Thus, in reality, the best evidence on the present-day associations between milk and dairy consumption and health and survival come from high-quality prospective studies.

Public health decisions need to be based on epidemiological evidence and not just on effects on selected markers of risk (Alvarez-León, Román-Viñas and Serra-Majem, 2006; Givens, 2010; Mozaffarian, 2011) and results interpreted in the context of all lifestyle issues such as dietary patterns (e.g. salt and fibre intake, consumption of fruit and vegetables etc.), physical activity, and smoking (Givens, 2010; Mozaffarian, 2011). In addition, it is important to consider the foods that are replacing dairy in the diets of people who choose to decrease dairy in their diets, i.e. the replacement foods and nutrients. For example, while replacing SFAs in the diet with polyunsaturated fatty acids (PUFAs) would be beneficial, replacing SFAs with refined carbohydrates such as sugars and starch may increase CHD risk (Mozaffarian, 2011).

Many studies do not distinguish between high-fat and low-fat dairy consumption, often because of inadequacies in the methods used to collect dietary data. Furthermore, consumption patterns may change from high to low fat when studies take place over long periods of time. Data from observational studies of consumption of fat-free and full-fat dairy products may be difficult to interpret even when available because people who choose to drink fat-reduced milk often adopt other "healthy" behaviours, such as taking physical exercise, reducing smoking etc., which affects their health status (Elwood *et al.,* 2010). This is especially true for comparisons of national food data with CHD incidence (German *et al.*, 2009; Gibson *et al.*, 2009). Although these lifestyle factors are often controlled for in statistical models, there may still be residual confounding factors (Tholstrup, 2006). Other discrepancies

may arise as a result of different populations consuming different types of dairy products; for example, low-fat vs high-fat milk, or cheese vs milk.

4.1.2 Interpreting study results

Interpreting results and formulating recommendations must take into account factors such as age, gender, health status, level of physical activity and genetic background of the targeted population. It is also important to keep in mind that the limited sensitivity of dietary assessment instruments may prevent detection of an effect of a single food in a mixed diet on clinical outcomes (Gibson *et al*., 2009). The cultural and geographical context is also an issue because of the wide variation in the average intake of dairy products; a high consumer in one context could be a low consumer in another (Alvarez-León, Román-Viñas and Serra-Majem, 2006). This highlights the need to express dairy consumption in consistent units: current expressions include pints, frequency per week, times per day and servings per week. Serving sizes differ between countries (Elwood *et al.,* 2010; Soedamah-Muthu *et al*, 2011) and the nutrient composition of dairy products may also vary between countries, depending on factors such as species and breeds of dairy animals (see Chapter 3) and different fortification policies.

4.2 MILK AS A SOURCE OF MACRO- AND MICRONUTRIENTS[17]

Milk intake may be a marker for diet quality because of its high nutrient content (Barger-Lux *et al*., 1992; Fulgoni *et al*., 2007). The macro- and micro-nutrient composition of whole (full fat) milk and skimmed cow milk are given in Table 4.1 and those of other dairy products are given in Table 4.2.[18]

Milk fat contributes about half of the energy in whole milk. For this reason, animal milk can play an important role in the diets of infants and young children in populations with a very low fat intake (Michaelsen *et al.,* 2011a), where the availability of other animal-source foods (ASF) is limited. However, it should be kept in mind that breast milk is also a key source of energy and essential fatty acids, and it is recommended that breastfeeding is continued, along with appropriate complementary foods, up to two years of age or beyond (WHO, 2003). Milk lipids are carriers of fat soluble vitamins. Milk fat contains approximately 400 different fatty acids, which make it the most complex of all natural fats (Månsson, 2008). The milk fatty acids are derived almost equally from two sources: the feed and the microbial activity in the rumen of the cow. Approximately 60 percent of the fatty acids are saturated. The effects of fat and fatty acids in milk on human health are reviewed in Section 4.7 *et seq.* and Chapter 5. Milk contains high-quality protein, defined as including all the essential amino acids needed by humans. Some milk proteins have been associated with allergies (see Section 4.10.2). Lactose, the principal carbohydrate in milk, will be discussed in Section 4.10.1.

[17] This section covers milk as a source of nutrients. Health implications, both positive and negative, are discussed elsewhere in this chapter and in Chapter 5.

[18] Although data are presented per 100 g, portion sizes will differ between foods; for example, a serving of milk or yoghurt may be 1 cup (250 ml = 250 g, since both milk and yoghurt have a density of ~1 g/ml), whereas a serving of cheddar cheese may be about 40 g. Both portion size and nutrient content need to be considered when making comparisons between foods.

TABLE 4.1

Nutrient content of full fat and skim milk (per 100 g) and comparisons with recommended nutrient intakes for children aged 4–6 years and females aged 19–50 years

Nutrient	Whole milk*	2 cups whole milk[1] vs RNI for children 4–6 yr[2]	2 cups whole milk vs RNI for females 19–50 yr	Non-fat milk[3]	2 cups non-fat milk vs. RNI for children 4–6 yr	2 cups non-fat milk vs. RNI for females 19–50 yr	RNI/day for children 4–6 yr	RNI for females 19–50 yr
Water (g)	87.69			90.84				
Energy (kcal)	64			34				
Energy (kJ)	268			142				
Protein (g)	3.28			3.37				
Lipid Total (g)	3.66			0.08				
Ash (g)	0.72			0.75				
Carbohydrate (g)	4.65			4.96				
Calcium (mg)	119	✓✓✓	✓	122	✓✓✓	✓	600	1 000
Iron (mg)	0.05	x	x	0.03	x	x	5 (12% bioavailability)	24 (12% bioavailability)
Magnesium (mg)	13	✓✓	x	11	✓✓	x	73	220 mg
Phosphorus (mg)	93			101				
Potassium (mg)	151			156				
Sodium (mg)	49			42				
Zinc (mg)	0.38	x		0.42	✓	✓	5.1 (moderate bioavailability)	4.9 (moderate bioavailability)
Copper (mg)	0.01			0.013				

TABLE 4.1 *(continued)*

Nutrient	Whole milk*	2 cups whole milk[1] vs RNI for children 4–6 yr[2]	2 cups whole milk vs RNI for females 19–50 yr	Non-fat milk[3]	2 cups non-fat milk vs. RNI for children 4–6 yr	2 cups non-fat milk vs. RNI for females 19–50 yr	RNI/day for children 4–6 yr	RNI for females 19–50 yr
Manganese (mg)	0.004			0.003				
Selenium (mcg)	2	✓	x	3.1	✓✓	✓	21 mcg	26 mcg
Vitamin C (mg)	1.5	x	x	0	x	x	30 mg	45 mg
Thiamin (mg)	0.038	x	x	0.045	x	x	0.6 mg	1.1 mg
Riboflavin (mg)	0.161	✓✓✓	✓✓	0.182	✓✓✓	✓✓	0.6 mg	1.1 mg
Niacin (mg)	0.084	x	x	0.094	x	x	8 mg Niacin Equivalents	14 mg
Pantothenic acid (mg)	0.313	✓	x	0.357	✓	x	3 mg	5 mg
Vitamin B_6 (mg)	0.042	x	x	0.037	x	x	0.6 mg	1.3 mg
Folate (µg)	5	x	x	5	x	x	200 mcg	400 mcg
Choline Tot				15.6				
Vitamin B_{12} (µg)	0.36	✓✓✓	✓✓	0.5	✓✓✓	✓✓✓	1.2 mcg	2.4 mcg
Vitamin A (RAE)	33	x	x	2	x	x	450 RE	500 RE

* USDA, Cow milk: Milk, producer, fluid, 3.7 percent milk fat (NDB No. 01078).

[1] Two cups =500 ml. Nutrient content in 2 cups of milk compared with the recommended nutrient values (RNIs) from FAO/WHO 2002.

[2] ✓✓✓ = 100 percent of RNI; ✓✓ = 70–99 percent of RNI; ✓ = 40–69 percent of RNI can be supplied by 2 cups of milk.

[3] USDA, Cow milk: Milk, non-fat, fluid, without added vitamin A and vitamin D (fat free or skim) (NDB No. 01151)

RNI: recommended nutrient values from FAO/WHO 2002.

RE= retinol equivalents in µg = µg retinol + 1/6 µg β-carotene + 1/12 µg other provitamin A carotenoids. USDA values are for retinol activity equivalents, i.e. µg retinol + 1/12 µg β-carotene + 1/24 µg other provitamin A carotenoids. However, for milk most of the vitamin A is in the form of retinol (and the separate values for β-carotene and other provitamin carotenoids are not available), so the USDA values may be directly compared with the recommended daily allowance (RDA) value.

TABLE 4.2

Contents of selected nutrients (per 100 g) of whole milk, skim milk and other dairy foods

USDA food name and food code	Energy (kcal)	Energy (kJ)	Protein (g)	Total Fat (g)	Carbohydrates (g)	Calcium (mg)	Sodium (mg)	SFA (g)	MUFA (g)	PUFA (g)	Cholesterol (mg)
Milk, producer, fluid, 3.7% milkfat (01078)	64	268	3.3	3.7	4.7	119	49	2.3	1.1	0.1	14
Milk, nonfat, fluid, without added vitamin A and vitamin D (fat free or skim) (01151)	34	142	3.4	0.1	5.0	122	42	0.1	0.0	0.0	2
Cream, fluid, light (coffee cream or table cream) (01050)	195	818	2.7	19.3	3.7	96	40	12.0	5.6	0.7	66
Cream, fluid, heavy whipping (01053)	345	1 443	2.1	37.0	2.8	65	38	23.0	10.7	1.4	137
Butter, without salt (01145)	717	2 999	0.9	81.1	0.1	24	11	51.4	21.0	3.0	215
Butter, salted (01001)	717	2 999	0.9	81.1	0.1	24	714	51.4	21.0	3.0	215
Butter oil, anhydrous (01003)	876	364	0.3	99.5	0.0	4	2	61.9	28.7	3.7	256
Milk, dry, whole, without added vitamin D (01212)	496	2 075	26.3	26.7	38.4	912	371	16.7	7.9	0.7	97
Milk, dry, nonfat, instant, without added vitamin A and vitamin D (01155)	358	1 498	35.1	0.7	52.2	1 231	549	0.5	0.2	0.0	18
Yoghurt, plain, low fat, 12 grams protein per 8 ounce (01117)	63	265	5.3	1.6	7.0	183	70	1.0	0.4	0.0	6
Yoghurt, fruit, low fat, 11 grams protein per 8 ounce (01122)	105	440	4.9	1.4	18.6	169	65	0.9	0.4	0.0	6

TABLE 4.2 *(continued)*

USDA food name and food code	Energy (kcal)	Energy (kJ)	Protein (g)	Total Fat (g)	Carbohydrates (g)	Calcium (mg)	Sodium (mg)	SFA (g)	MUFA (g)	PUFA (g)	Cholesterol (mg)
Frozen yoghurts, chocolate (42186)	127	531	3.0	3.6	21.6	100	63	2.3	1.0	0.1	13
Milk, buttermilk, fluid, cultured, lowfat (01088)	40	169	3.3	0.9	4.8	116	105	0.5	0.3	0.0	4
Cheese, cheddar (01009)	403	1 684	24.9	33.1	1.3	721	621	21.1	9.4	0.9	105
Cheese, cream (01017)	342	1 431	5.9	34.2	4.1	98	321	19.3	8.6	1.4	110
Cheese, cottage, nonfat, uncreamed, dry, large or small curd (01014)	72	303	10.3	0.3	6.7	86	330	0.2	0.1	0.0	7
Cheese, cream, fat free (01186)	105	441	15.7	1.0	7.7	351	702	0.6	0.3	0.1	12
Cheese food, pasteurized process, swiss (01047)	323	1 352	21.9	24.1	4.5	723	1 552	15.5	6.8	0.6	82
Ice creams, vanilla (19095)	207	868	3.5	11.0	23.6	128	80	6.8	3.0	0.5	44

SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids.
Source: USDA, 2009.

Milk can make a significant contribution to the required nutrient intakes for calcium, magnesium, selenium, riboflavin, vitamin B_{12} and pantothenic acid (see Table 4.1). Food of animal origin, including milk and dairy products, can be an important source of zinc and vitamin B_{12} in children at risk for micronutrient deficiencies (Neumann, Harris and Rogers, 2002). Milk is low in sodium. Bioavailability of some nutrients in milk, for example calcium, is high compared with that in other foods in the diet (Weaver, Proulx and Heaney, 1999). Milk does not contain substances that inhibit mineral bioavailability, such as phytates and oxalates. When milk is consumed together with foods containing inhibitors, calcium absorption is decreased slightly by oxalates but little affected by phytates (Weaver, Proulx and Heaney, 1999). In addition, milk is thought to contain constituents that enhance mineral absorption, such as lactose and certain amino acids, but absorption of minerals from cow milk has not been demonstrated to be greater than that from mineral salts (Weaver and Heaney, 2006).

Cow milk does not contain appreciable amounts of iron (Dror and Allen, 2011). Consumption of fresh, unheated cow milk by infants prior to 12 months of age is associated with faecal blood loss and lower iron status (Ziegler *et al*., 1990; Griffin and Abrams, 2001). There is evidence that high intakes of calcium interferes with iron absorption, although inhibition of iron has been reported only in single-meal studies (Dror and Allen, 2011); over longer periods of time adaptive mechanisms may negate the single-meal effect (Minihane and Fairweather-Tate, 1998). Compared with breast milk, cow milk also presents a high renal solute load to infants, owing to its higher contents of minerals and protein. International guidelines and most national policies recommend exclusive breastfeeding up to six months of age: according to WHO guidelines, no undiluted cow milk should be given to infants up to 12 months of age unless accompanied by iron supplements or iron-fortified foods, although dairy products such as cheese and yoghurt may be fed to infants more than six months old (WHO, 2003; WHO, 2004).

Constituents in milk that are not identified as essential nutrients but that are now being studied for their health-promoting properties are discussed in Chapter 5.

4.3 DIETARY DAIRY IN GROWTH AND DEVELOPMENT

Nutrition and health in the first two to three years of life are important for growth and development of children, with most growth faltering occurring during this time (Grillenberger *et al*., 2006). However, "catch-up growth" remains possible in school-aged children and even adolescents when factors that impair growth are eliminated (Grillenberger *et al.,* 2006). Stunting is associated with increased child morbidity and impaired cognitive development (Hoppe, Mølgaard and Michaelsen, 2006). Stunting, along with low birth weight, is also a risk factor for chronic disease in adulthood (Popkin, Horton and Kim, 2001). Therefore, greater growth is associated with better child health and development. Taller adult stature has been associated with reduced risk of cardiovascular disease (Hoppe, Mølgaard and Michaelsen, 2006). However, taller adult stature is not always associated with better health. For example, the WCRF panel concluded that there is convincing evidence that the factors that lead to greater adult attained height, or its consequences, increase the risk of cancers of the colorectum and breast (postmenopause), and probably also increase the risk of cancers of the pancreas, breast (premenopause) and ovary

(WCRF and AICR, 2008a, 2008b). Height is also generally accepted to be a risk factor for osteoporotic fractures (Hannan *et al*., 2012, and references therein). Current evidence suggests that there may be particular periods in which growth is associated with better adult health, while rapid growth in other stages may result in an increased risk of non-communicable diseases (NCDs): findings from the Helsinki Birth Cohort Study of over 13 000 children born between 1934 and 1944 in Helsinki who went on to develop CHD, hypertension and diabetes as adults showed that these children were more likely to be generally short and thin at birth, have poor growth in the first year of life but then accelerated weight gain in later childhood, although their heights remained below average (Eriksson *et al*., 2000; Eriksson *et al*., 2001; Eriksson *et al*., 2003; Forsen *et al*., 2004; Eriksson, 2011). A recent paper from the group (Eriksson, 2011) stresses that "not only a small body size at birth but also slow growth during infancy increased the risk of CHD in later life. Low weight at one year old added to the CHD risk independently of body size at birth". However, the author concludes that these findings need to be replicated in younger contemporary cohorts before public health initiatives can be proposed.

Recent review studies are available on the role of ASF, including milk, in the diets of children in low-income countries (Allen and Dror, 2011; Dror and Allen, 2011). In observational studies, a higher intake of ASF has been associated with better growth, micronutrient status, cognitive performance, motor development and activity in children, although the effects on cognitive function and activity were more pronounced in children consuming meat rather than milk. Cow milk is a source of vitamin B_{12}, a micronutrient commonly deficient in populations that consume low amounts of ASF, and can thus help to improve children's nutritional status. Furthermore, milk can be used as a fortification vehicle for micronutrients (Allen and Dror, 2011; Dror and Allen, 2011).

A meta-analysis of seven randomized controlled trials and five non-randomized controlled trials examining the relationship between consumption of dairy products and physical stature in children and adolescents aged 3–13[19] has been published recently (de Beer, 2012). Sample sizes in the trials varied from 36 to 757 participants and study duration varied from 3.3 to 24 months. Seven studies were conducted since the 1990s, and the rest were conducted between 1926 and 1980. While two trials included moderately or severely stunted children, most trials included children who were only slightly or not at all stunted. Five of the studies were in developed countries while the rest were from developing countries (two in China, one in northern Viet Nam, one in Kenya, two in Indonesia and one in India). In eight studies, children received 190 to 568 ml of whole or skimmed milk daily, while in the other studies diets were supplemented with (reconstituted) milk powder, cheese and yoghurt. The authors conclude that the most likely effect of supplementing children's diets with dairy products is 0.4 cm additional growth per year for every 245 ml of milk added to the diet (95 percent confidence interval [CI]: 0.22–0.58), which is the effect of an intervention of 12 months on average. Nutritionally deprived children (shorter height-for-age) benefited more from supplementation

[19] The search criteria were for age group 2–18 years.

than their better-fed peers, and teenagers (children close to or just in their pubertal growth spurt) also benefited more.

Childhood growth can be separated into growth during infancy, childhood and puberty (Karlberg, 1987). However, the design of most studies does not allow one to distinguish between the prepubertal period (with a relatively low growth velocity) and puberty (when growth velocity varies considerably and includes the peak height-growth velocity). Therefore, in the following sections we first present studies on preschool children, followed by studies on school-aged children (including pre-, peri- and postpubertal children). In preschool children, growth velocity is still high (especially during the first years) and an effect of cow milk might be more pronounced during this period (Hoppe, Mølgaard and Michaelsen, 2006). We separately address the effects of milk/dairy on (linear) growth in undernourished children and well-nourished children. We focus on studies dealing with linear growth (rather than cognitive growth or weight), although weight changes when reported as part of those studies are included.

Chapter 7 discusses the role of ASF, and in particular milk, with respect to energy, protein, micronutrients and essential fatty acids and childhood growth.

4.3.1 Studies on the effect of milk and dairy products on linear growth in undernourished or socio-economically underprivileged children

Preschool children

Intervention studies

He *et al.* (2005) reported the results of a randomized controlled trial (RCT) carried out in Beijing that involved 402 preschool children (aged three to five years) whose height-for-age and/or weight-for-age were less than the reference level. The children were divided randomly into a yoghurt supplemented group (125 g yoghurt for five days a week) or control group (no supplementation). Children in the yoghurt-supplemented group gained significantly more height than those in the control group after receiving yoghurt for three, six and nine months ($P<0.05$) (1.90±0.49 cm vs 1.77±0.54 cm, 3.83±0.57 cm vs 3.64±0.66 cm and 5.43±0.69 cm vs 5.24±0.76 cm, respectively). The children in the yoghurt group also gained significantly more weight than those in control group after receiving yoghurt for three, six and nine months ($P<0.05$).

A prospective, longitudinal assay of 227 children in Mexico aged 8–60 months reported that supplementing their diet with 500 ml of milk fortified with multiple micronutrients daily for 90 days significantly improved the nutritional status and weight-for-height Z scores of the children and reduced the number of malnourished children (Maulen-Radovan *et al.*, 1999). Unfortunately, the study did not include a control group.

Observational studies

Observational studies from developing countries also show positive associations between milk consumption and linear growth in preschool children. Demographic and health survey data on preschool children from 12 to 36 months old in seven countries in Central and South America showed that milk consumption was significantly associated with higher height-for-age Z scores in all seven countries, whereas intakes of meat, eggs, fish and poultry were only associated with height

increases in only one of the countries (Ruel, 2003). Allen *et al.* (1992) looked at longitudinal data from 67 Mexican children aged 18–30 months and found that diets of taller children contained more animal products, including milk, than did diets of shorter children.

School-aged children

Intervention studies

The classic Boyd Orr study (or Carnegie survey) was carried out in the beginning of the last century among 1 343 mainly working class families, and examined the effects of supplementing the diets of 5- to 14-year-old Scottish children at school with whole milk, skimmed milk or biscuits that contained an equivalent amount of energy, compared with a control group receiving no supplements (Orr, 1928). Those receiving either type of milk gained an average of 20 percent more height in seven months (Orr, 1928), but only children who continued to receive milk supplements sustained higher rates of growth (Leighton and Clark, 1929). Because this study was conducted in pre-war Britain, it is plausible that some degree of malnutrition was present in the children at the onset of the study (Hoppe, Mølgaard and Michaelsen, 2006), and the effect of milk on growth may have occurred because of a correction of nutrient deficiencies. Hoppe, Mølgaard and Michaelsen (2006) also refer to work carried out by Spies and co-workers in the United States on a selected group of 82 children with chronic nutritive and growth failure (Spies *et al.*, 1959). The three-year study, initiated in 1945, looked at the effect of daily supplementation with either whole or non-fat dried milk on the growth in the intervention group compared with a control group. The children receiving the milk supplements gained an average of 1.23 cm more height than the control group during the supplementation period (Hoppe, Mølgaard and Michaelsen, 2006).

A limited number of RCT studies are currently available. One RCT was carried out on 33 children in New Guinea aged 6–15 years old who had very low protein diets. The majority of the children were below the third percentile in height at the beginning of the study even though the Bundi people of New Guinea have a reliable supply of food throughout the year from their staple crops of taro and sweet potato (Lampl, Johnston and Malcolm, 1978). Three groups of children were given diets supplemented with skim milk powder (75 g/day), margarine with an equivalent amount of energy or extra servings of taro and sweet potatoes over a 13-week period, and compared with a control group who received no supplementary food. The linear growth of children receiving the skim milk supplements was nearly twice as fast as that of children in the other groups (Lampl, Johnston and Malcolm, 1978).

An RCT was carried out in rural Viet Nam, in a region where the prevalence of stunting was 50 percent. Schoolchildren (7–8 years old) were provided with 500 ml of unfortified milk on school days for six months (Lien do *et al.*, 2009). The control group received no supplementation. Height gain was 0.4 cm greater and weight gain 0.5 kg greater in the milk intervention group than in the non-intervention control group, although these differences were not significant. However, both weight-for-age and height-for-age significantly improved over the six months that milk was provided, and as a consequence the incidence of underweight and stunting dropped by roughly 10 percent.

Another RCT evaluated the growth of 544 children aged 5–14 years (median age 7.1 years) in rural Kenya after 23 months on a diet supplemented with a meat, milk (200 ml/day) or energy supplement compared with a control group that received no supplement. Children in each of the supplementation groups gained significantly more weight (about 10 percent) than the control group. No statistically significant overall effects of supplementation were found on height, height-for-age Z score, weight-for-height Z score or measures of body fat. However, in a subgroup of children whose height-for-age Z score was below median at baseline, milk supplementation led to a statistically significant increase in height gain of 1.3 cm (15 percent) compared with the control group (P=0.05) and 1 cm (11 percent) more height than those in the group receiving the meat supplement (P=0.09) (Grillenberger *et. al.*, 2003).

An RCT study in South Wales, United Kingdom, probed the effect on growth of the provision of free milk supplements to schoolchildren of seven and eight years old (Baker *et al.*, 1980). The children included were "those whose socio-economic circumstances might place them at a disadvantage for growth". The results showed that height and weight gain associated with the provision of free milk was very small in the study population: the milk group grew only 2.9 mm more than the control group, although this was significant (P<0.05). The authors concluded that it is therefore likely that the benefit to growth of providing free milk to all schoolchildren of these ages would be even smaller. According to the authors, the limited increase in growth of subjects in the group receiving milk probably reflects a reasonable state of general nutrition even in this "disadvantaged" population (Baker *et al.*, 1980).

Observational studies

A study in Malaysia followed a large sample of 2 766 children of 6–9 years old who participated in a school milk programme that provided each child with 250 ml of milk twice weekly (Chen, 1989). The study found a reduction in the prevalence of protein–energy malnutrition in terms of underweight (15.3 percent to 8.6 percent), stunting (16.3 percent to 8.3 percent) and wasting (2.6 percent to 1.7 percent) over a 21-month period from the start of the school feeding programme. As there was no major development in this region during this time period, these positive effects were ascribed to the impact of the school milk feeding programme.

However, other observational studies have found no effect of milk supplementation on growth: studies of UK schoolchildren in the 1970s and 1980s found no consistent associations between supplying milk in the schools and rates of growth in children aged 5–9 years, even when stratified by poverty status and ethnic background (Rona and Chinn, 1989). Data from England and Scotland in 1972–76 were used to investigate the effect of the availability of free school milk on height gains in one year among 6–7 year olds (Cook *et al.*, 1979). In this large longitudinal study, the sample of areas was weighted to include poorer areas. This study showed that children with access to free milk did not grow significantly more in height than did those without access. Even when data from children from the manual labourer social classes were analysed, 13 out of 16 sex–country–year-specific analyses showed no significant evidence of greater height gain in children who had access to free milk.

Although not unequivocally supported by the evidence, milk appears to have a positive effect on growth among nutritionally or socio-economically disadvantaged children. The strongest effects may be seen on the growth of children with exist-

ing undernutrition (Wiley, 2005; Hoppe, Mølgaard and Michaelsen, 2006; de Beer, 2012). Although current evidence suggests that these effects may be more apparent during the first few years of life, too few studies are available on preschool children to draw any conclusions.

4.3.2 The role of milk and dairy products in treatment of undernutrition

Milk plays a key role in treating undernutrition both in industrialized countries (where almost all products used for enteral feeding of malnourished hospitalized children and adults are milk-based [Michaelsen *et al*., 2011a]) and in developing countries. A diet that contains sufficient milk or dairy to provide 25–33 percent of the daily protein requirement (which is about 200–250 ml milk or 15–20 g of milk powder or whey protein powder per 1 000 kcal) may have a positive effect on weight gain and linear growth in children aged six months to five years who are suffering from moderate malnutrition (Michaelsen *et al*., 2009). When cow milk is used in the treatment of undernutrition it is generally in the form of a powdered ingredient. Chapter 7 covers these products. The components of milk that are thought to be particularly important to growth in undernourished children are protein (including peptides and other bioactive factors), minerals (phosphorus, in particular) and lactose, as cow milk fat is not usually included in products to treat undernutrition (Michaelsen *et al*., 2011a). The high lactose content might support growth by contributing to improved absorption of minerals and providing a prebiotic effect (Michaelsen *et al*., 2011a).

Other dairy products have also been used successfully in the treatment of moderate malnutrition in children. Fermented milk (and yoghurt) has been suggested to be a good alternative to fresh milk as it has a nutritional content similar to fresh milk (apart from less lactose); it also keeps better so the risk of growth of pathogenic bacteria is reduced (Michaelsen *et al*., 2011a). "Filled milk", which is a powdered product based on skimmed milk and vegetable oil, has the advantage that it is cheaper than whole-milk powder and the replacement of milk fat with vegetable oil could be beneficial from a nutritional point of view, depending on which vegetable oil is added, by reducing the levels of *trans* fatty acids (TFAs) and SFA. Whey powder (with a protein content of 13 g/100 g of product) or whey protein concentrate (which commonly has a protein content of either 35 g or 80 g/100 g of product) can be used in the preparation of special foods or blends for malnourished children. Since whey is a by-product of cheese-making, it has been cheaper than dried skimmed milk per unit of protein, although prices have been fluctuating in recent years. Skim milk, or milk with a reduced fat content (<2 percent), should not be given to children unless complemented with foods that boost fat intake to the recommended level; milk with reduced fat content also has a high renal solute load in relation to its energy content. Although powdered milk is often cheaper and more easily available than liquid milk, it carries the risk of contamination during reconstitution. Evaporated milk and condensed milk should not be used as a drink but can be mixed into porridge and other foods (Michaelsen *et al*., 2009). Chapter 7 presents an overview of programmes that use milk powder and blended foods and their impact on human nutrition in developing countries.

Oakley *et al.* (2010) recently published the results of a randomized, double-blind, controlled, clinical, quasi-effectiveness trial of isoenergetic amounts of two locally produced ready-to-use therapeutic foods (RUTF) to treat severe and acute

malnutrition in Malawian children aged 6–59 months. A total of 1 874 children were enrolled in the study. Children were randomly assigned to either 25 percent milk RUTF or 10 percent milk RUTF as home-based therapy for up to eight weeks. The primary outcome was recovery (weight-for-height Z score >–2 and no oedema). Secondary outcomes were rates of weight and height gain. Recovery among children receiving 25 percent milk RUTF was greater than among children receiving 10 percent milk RUTF (64 percent compared with 57 percent after four weeks, and 84 percent compared with 81 percent after eight weeks [$P<0.001$]). The rates of weight and height gain were also greater among children receiving 25 percent milk RUTF than those among children receiving 10 percent milk RUTF.

4.3.3 Milk in the diets of well-nourished children

In general, the protein intake of children in industrialized countries is considerably above basic physiological requirements (Hoppe, Mølgaard and Michaelsen, 2006). As the effect of milk on growth in well-nourished children is likely to be via a mechanism that is different to that in undernourished children (see Section 4.3.5), data on well-nourished children are considered separately.

Preschool children

Associations between milk consumption and height among 1 002 preschool-aged children aged 24–59 months was studied in the United States using data from the National Health and Nutrition Examination Survey (NHANES) covering 1999–2002 (Wiley, 2009). Children who drank milk daily were significantly taller (1.0 cm; $P<0.02$) than those with less frequent intake. Consumption of other dairy products had no association with height. The author concluded that "Similarly positive effects of milk on height have not been found routinely in older prepubertal children, suggesting that the growth of children in this age group may be particularly responsive to milk intake". Wiley (2009) suggests that the positive association between milk and height among very young children may reflect a growth pattern attuned to milk consumption, i.e. evolutionarily children in this age group would still be consuming some breastmilk and are growing rapidly and can thus convert milk's nutrients and other qualities into linear growth. Alternatively, young children may be physiologically more sensitive to milk's properties or they may simply show more variability in growth (Wiley, 2009).

A study of 90 healthy and well-nourished 2½-year-old Danish children found that height was positively associated with intakes of animal protein and milk (mean intake 385 ml of milk/day) (Hoppe, Mølgaard and Michaelsen, 2006).

School-aged children

Intervention studies

Du *et al.* (2004) carried out a two-year milk intervention trial involving 757 10-year-old girls in Beijing.[20] Schools were randomized into three groups, where the first

[20] Although this study was carried out in China, the children were not reported to be undernourished, even though low baseline milk and calcium intakes were observed.

group consumed a carton of 330 ml of milk fortified with calcium each school day over the study period; the second group of girls received the same quantity of milk additionally fortified with 5 mg or 8 mg of cholecalciferol; the third was a control group and received no milk. When the relative percentage changes (the percentage changes from baseline, rather than the absolute values) were considered, the increases in height, sitting height and body weight after two years of the girls in the two supplemented groups were significantly greater than those of the girls in the control group. When the data were adjusted for menarcheal status, the effects of the milk supplement on bone were still apparent.

In an American study, a group of healthy young Caucasian females with an average baseline age of 10.8 years were followed for seven years, to cover the pubertal growth spurt and late adolescence (Matkovic *et al.*, 2005). One cohort participated in a long-term double-blinded, placebo-controlled clinical trial with calcium supplementation, and the other participated in an observational study with higher calcium intakes from dairy products. By an average age of 15 years, the dairy-group subjects remained significantly taller ($P<0.01$) and had higher dietary calcium and protein intakes than the calcium-supplemented and placebo groups.

In a double-blind, placebo-controlled study, 149 healthy prepubertal girls of mean age of 7.9 years each day for one year received either two food products fortified with 850 mg of calcium from milk extract or the same food products that had not been fortified (placebo) (Bonjour *et al.*, 1997). The ratio of the gains in height in the calcium-supplemented group over those in the placebo group as calculated from the means of the individual differences recorded at 48 weeks and at baseline was 1.08 cm. The difference in gains between calcium-supplementation and placebo groups was greatest in girls with a spontaneous calcium intake below the median of 880 mg/day. The absolute differences in size gains recorded at the end of the intervention period were still detectable one year after termination of the dietary intervention. However, it is not clear if these differences were statistically significant.

Other intervention studies have failed to show a significant effect of milk or dairy intervention. For example, Wiley (2005) catalogues a number of milk intervention studies on well-nourished children aged between 6–16 years in developed countries (i.e. Chan *et al.*, 1995; Cadogan *et al.,* 1997; Bonjour *et al.*, 1997; Merrilees *et al.*, 2000; Bonjour *et al.*, 2001; all cited in Wiley, 2005), but notes that none has been able to demonstrate a statistically significant positive effect of milk on growth in height.

Observational studies

A large prospective cohort study (Berkey *et al.*, 2009) studied 5 851 girls who were premenarchal at baseline and aged nine years or older for up to eight years of follow-up. Premenarchal girls who drank more than three servings of milk per day grew 0.11 inches more ($P=0.02$) the following year than girls consuming less than one serving per day on average. Yoghurt (+0.13 inches/cup; $P=0.02$), but not cheese or total calories, predicted height growth. In a separate model, dairy protein (+0.034 inches/10 g; $P<0.001$) predicted height growth. Dairy protein was more important than dairy fat for all outcomes. Nondairy animal protein and vegetable protein were never significant, nor were nondairy animal fat and vegetable fat. According to the authors, these findings suggest that a factor in the nonlipid phase of milk, but not protein itself, has growth-promoting action in girls. They

suggest that the protein in milk maybe a marker for other factors in the nonlipid component of milk.

Another study looked at milk consumption and height in American children by analysing NHANES data from 1999–2002 (Wiley, 2005). For adults, data on early consumption were obtained from questions about milk consumption in childhood. Results indicated that adult height was positively associated with milk consumption at ages 5 through 12 years and 13 through 17 years. For children (5–18 years), two types of data were used: participants rated the frequency of their milk intake in the last 30 days and information was gathered from a 24-h dietary recall, which provided a snapshot of current milk intake. Among these children, frequency of milk consumption over the past 30 days had no effect on the height of 5–11-year-olds, but 30-day frequency of milk consumption and milk intake (measured as grams of milk, or protein or calcium from milk) were significant predictors of the height of 12–18-year-olds, along with age, gender, household income and ethnicity. However, the authors note that the effect of milk on height was modest (Wiley, 2005).

A study of 250 children in New Zealand aged 3–10 years found that long-term avoidance of cow milk was associated with small stature and poor bone health (Black *et al*., 2002). Similar results were reported by Rockell *et al*. (2005), who followed changes over two years of a group of 46 Caucasian children in the United States with an initial mean age of 8.1 years. The children had low calcium intakes at baseline and were short in stature. At follow-up, modest increases in milk consumption and calcium intake had occurred. Although some catch-up in height had taken place, the group remained significantly shorter than the reference population of milk-drinking children from the same community (Z scores −0.39±1.14). A longitudinal study conducted in Japan involving 92 children, average age 9.5 years, reported that the mean height gain in those consuming more than 500 ml of milk/day was greater than that of those consuming less than 500 ml/day; the difference in height gain between the two groups was 2.5 cm over three years (Okada, 2004).

In conclusion, much of the evidence suggests that milk promotes linear growth in well-nourished children, although gains may be modest and not always statistically significant. The two available studies on well-nourished preschool children suggest that this effect may be more pronounced in younger children.

4.3.4 Secular trend of increasing adult height

During recent decades, adult height has increased steadily in most European countries and in the United States (see Hoppe, Mølgaard and Michaelsen, 2006 and references therein). These changes have been ascribed to a general improvement in living conditions, accompanied by a change in nutritional status and food consumption patterns, including a greater consumption of milk and other ASFs. The secular trend in height in Japanese children has been mainly ascribed to increased milk consumption: regional differences in height were found to correspond to milk consumption in the national school lunch programme in Japan (Takahashi, 1984). These results are consistent with the observation that nomadic or pastoral people living on milk in arid areas are usually taller than people whose livelihoods are cultivation-based (Takahashi, 1984).

A recent study conducted in India on a large nationally representative sample of people shows that a secular trend in adult height has also begun to occur in some

developing countries (Mamidi, Kulkarni and Singh, 2011). The study found that men and women from the northern states were generally tallest and those from the northeastern states shortest. The percentage of the population consuming milk or curd was highest in the northern states and lowest in the northeastern states. Analysis of socio-economic factors showed that people who lived in urban areas, who were more educated and who belonged to the highest income group were taller and had greater increments in height per decade. These findings may have important policy implications for developing countries such as India that have a high prevalence of stunting and a modest secular increase in height.

As summarized by de Beer (2012) in the recent systematic review and meta-analysis, "In conclusion, there is moderate quality evidence that dairy products supplementation stimulate linear growth supporting hypotheses that changing levels of consumption of dairy products in the 19th and 20th centuries contributed to trends in height".

4.3.5 Possible mechanisms for growth-stimulating effects of milk

Milk is a source of energy, although the number of calories varies with fat content. Although many of the nutrients in milk are likely to contribute in specific ways to the overall growth process, most research has focused on two components in milk as particularly important to bone growth, calcium and insulin-like growth factor-1 (IGF-1) (Wiley, 2005; Wiley, 2009). (The role of calcium is discussed in Section 4.4) In the skeleton, IGF-1 acts to increase the uptake of amino acids, which are incorporated into new proteins and thereby contribute to growth in bone length (Cameron, 2002, cited in Wiley, 2005).

In children with poor nutritional status, the addition of milk to the diet is likely to supply nutrients that are important for growth and are deficient in the diet (Hoppe, Mølgaard and Michaelsen, 2006). In well-nourished children, the effect of milk on linear growth is likely through stimulation of IGF-1 rather than through correcting nutrient deficiencies (Hoppe, Mølgaard and Michaelsen, 2006). Synthesis of IGF-1 is regulated by both growth hormone and nutrition; it is likely that nutritional regulation of IGF-1 is more important during infancy, when IGF-1 concentrations are low, than later in childhood and in adulthood (Hoppe, Mølgaard and Michaelsen, 2006). Milk intervention trials in children have been associated with increased circulating IGF-1 (Cadogan *et al.*, 1997; Hoppe *et al.*, 2004). Although cow milk contains IGF-1, this growth factor consumed orally is not absorbed (Larsson *et al.*, 2005). It is currently speculated that bioactive peptides, milk IGF-1, amino acids (especially the branched-chain amino acids leucine, isoleucine and valine) or milk minerals (in particular calcium and zinc) are involved in stimulating the insulin-like growth factors (IGFs) (Hoppe, Mølgaard and Michaelsen, 2006).

Understanding the complex interrelationships between IGF and milk is of interest because IGF-1 levels may be related (both positively and negatively) to mortality and risk of several NCDs, such as cancer (see Section 4.9) (Hoppe, Mølgaard and Michaelsen, 2006; van der Pols *et al.*, 2007; van der Pols *et al.*, 2009; Martin, Holly and Gunnell, 2011). A longitudinal analysis of the Boyd Orr cohort looked at possible "programming effects" of childhood dairy and calcium intake and CVD mortality in adulthood (van der Pols *et al.,* 2009). The study traced 88 percent of the original children. The authors found no strong evidence to suggest that a childhood diet high

in dairy products was associated with CHD or stroke mortality, although childhood calcium intake was inversely associated with stroke mortality. Childhood diets rich in dairy or calcium were associated with lower all-cause mortality in adulthood, independent of childhood height (a marker for IGF levels in childhood), which suggests that the IGF pathway was not involved as an underlying mechanism. However, the authors speculate that childhood diets may have had long-term programming effects on adult IGF-1 levels, which may not be reflected by childhood height.

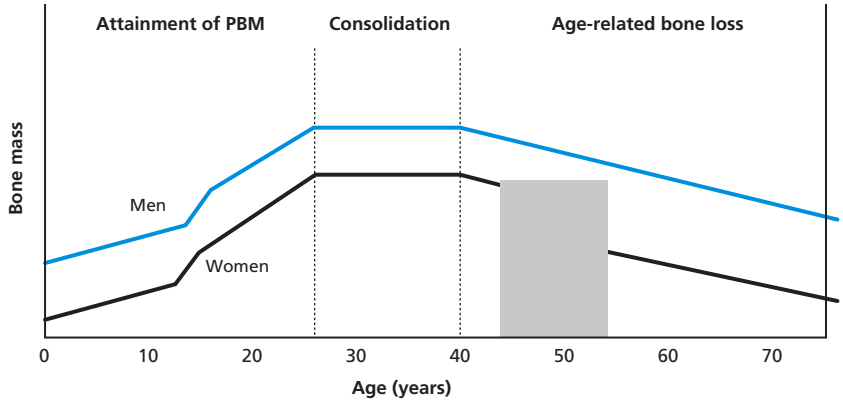
4.4 DIETARY DAIRY AND BONE HEALTH

4.4.1 Bone growth

The process of bone resorption and bone formation is termed bone remodelling. This process takes place throughout life, although at different rates at different times (Figure 4.1).

Bone mass increases rapidly during adolescence (Figure 4.1). During this period of rapid growth, approximately half of adult peak bone mass (PBM) is accumulated (Heaney *et al*., 2000) and bone turnover rates are high, with bone formation exceeding bone resorption rates. Bones elongate and height increases under the control of genes that programme body size through changes in sex steroid hormones and growth hormones (Weaver, 2002). There is a lag period between peak height velocity and peak bone mineral content velocity when children in early puberty have relatively low bone mass (Bailey *et al*., 1999). This is consistent with a period of high incidence of fracture (Khosla *et al*., 2003). Peak bone mass (the maximum amount of bone mass attained during a person's life) can be reached as early as the late teenage years or as late as mid-thirties, depending on skeletal site (Theobald, 2005). A 10 percent increase in PBM is associated with a 50 percent reduction in risk of osteoporotic fracture (Bonjour *et al*., 2003, cited in Theobald, 2005). From

FIGURE 4.1
Changes in bone mass during the human life cycle



Critical times are: (1) attainment of peak bone mass (PBM: 0–28 years of age, with pubertal years being particularly crucial); (2) menopause (■; during the menopause and ≤ 10 years post menopause it is estimated that 1–2 percent of bone is lost per year); (3) age-related bone loss (a low bone mineral density threshold increases osteoporosis fracture risk).
Source: Lanham-New, 2008.

PBM until menopause in women or old age in men, bone is considered more stable, although increasing evidence shows bone loss begins much earlier than menopause, especially in sedentary individuals (Weaver *et al*., 2001). Bone loss is common in the aging skeleton. Bone turnover increases with the loss of oestrogen and, as in puberty, bone formation and bone resorption becomes uncoupled. At this life stage, bone resorption rates exceed bone formation rates. The magnitude of bone loss is highly dependent on body weight. Smaller skeletons are more vulnerable to loss, likely because their bones are less loaded with lower body weight and therefore provide less mechanical stimulus. Overall, genetics are thought to control 60–80 percent of bone mass and environmental factors such as diet and physical activity 20–40 percent (Krall and Dawson-Hughes, 1993; Bonjour and Chevalley, 2007).

4.4.2 Dietary factors that affect bone health

The main dietary factors that affect bone mass are calcium and vitamin D, although other nutrients such as potassium, zinc, vitamins A, C and K and protein, as well as energy, also play a role. Calcium, phosphorus and magnesium are the most important minerals to bone health, of which calcium is the most abundant. More than 99 percent of the body's calcium, 85 percent of its phosphorus and 60 percent of its magnesium are in bone.

Calcium

Calcium balance is determined by the relationship between calcium intake and calcium absorption and excretion. Dietary intake of calcium has to be large enough to match obligatory losses, if skeletal damage is to be avoided. About 20–30 percent of calcium consumed in the diet is absorbed in the gastrointestinal tract (Theobald, 2005). The amount absorbed depends on the form in which calcium is present in food (e.g. insoluble complexes with phosphate), the amount present, its solubility and the presence of dietary factors that inhibit or promote absorption (e.g. phytates and oxalates inhibit absorption by forming insoluble salts). Protein has both positive and negative effects on calcium balance (see "Protein", below). Calcium bioavailability is also influenced by physiological variables such as historical calcium intakes, vitamin D status (see "Vitamin D", below) and age (absorption appears to decline with age), pregnancy and lactation status (calcium absorption is up regulated during lactation) (FAO and WHO, 2002; Theobald, 2005).

The FAO/WHO expert consultation on vitamin and mineral requirements (FAO and WHO, 2002) presented recommendations for calcium intakes based on long-term[21] calcium-balance data for adults in Western countries (Table 4.3).[22] The consultation noted that mean calcium requirement of adults at present can only

[21] The mean duration of the 210 experiments from eight publications used in this report to derive the recommended intakes was 90 days with a range of 6–480 days. (The four 6-day balance studies in the series used a non-absorbable marker and are therefore acceptable).

[22] The report states that other possible beneficial effects of calcium, such as in the prevention or treatment of pre-eclampsia, colon cancer or hypertension, have not been considered in making these recommendations, as experimental results in these regards have been disappointing/inconclusive or negative.

be determined by balance studies conducted with sufficient care, and over a sufficiently long period of time to ensure reasonable accuracy and then corrected for insensible losses. The calcium requirement was reported to change depending on other nutrients present in the diet, two such nutrients being sodium (presumably competing with calcium for reabsorption in the renal tubules) and animal protein (see "Protein", below, for possible mechanisms), both of which increase urinary calcium and were therefore presumed to increase calcium requirement. Vitamin D also plays a role in calcium homeostasis and calcium absorption. The expert consultation also highlighted the "calcium paradox", that hip fracture rates are higher in developed countries, where calcium intake is high, than in developing countries, where calcium intake is lower,[23] and suggested that this may be related to protein intake and vitamin D status in these countries, or both, with sodium intake being another possible reason. Hence, the expert consultation provided different recommendations for countries with low consumption of animal protein (20–40 g/day rather than the 60–80 g/day typical of developed countries) (Table 4.3).

A subsequent WHO/FAO expert consultation on diet, nutrition and the prevention of chronic diseases (WHO and FAO, 2003) concluded that there is convincing evidence that sufficient intake of vitamin D and calcium together reduces the risk of osteoporotic fracture in older people. Based on the findings of FAO and WHO (2002), WHO and FAO (2003) recommended a minimum daily intake of 400–500 mg of calcium in countries with a high incidence of fracture to prevent osteoporosis (WHO and FAO, 2003). This recommendation was made after considering the strength of the evidence with fracture as an end point (rather than BMD; see Section 4.4.5 for limitations of studies using BMD as an end point), and appears to relate to older people (>50-60 yr). This is considerably lower than the amounts recommended by the previous expert consultation (Table 4.3). The experts further stated that recommendations for calcium intake in countries with low fracture incidence should take into account the interaction between calcium intake, physical activity, sun exposure and intake of other dietary components (e.g. vitamin D, vitamin K, sodium, protein) and protective phytonutrients (e.g. soy compounds).

Vitamin D

Calcium and vitamin D interact in the human body: when the level of ionized calcium in the blood falls, parathyroid hormone is secreted by the parathyroid gland, stimulating the conversion of vitamin D to its active form, calcitriol (1,25-dihydroxyvitamin D) and thus depleting vitamin D status (measured by the amount of the inactive form). Vitamin D, as calcitriol, influences calcium absorption across the intestine, and inadequate vitamin D status is associated with reduced absorption of calcium from the diet. Vitamin D can either be made in the skin from a cholesterol-like precursor by exposure to sunlight or can be provided preformed in the diet; from a nutritional perspective, the two forms are metabolized similarly in humans, are equal in potency and can be considered equivalent (FAO and WHO, 2002).

[23] Average total calcium intakes in Africa, Latin America, the Near East and the Far East are less than 500 mg/day; the average total calcium intake for all developing countries is only 344 mg/day (FAO/WHO, 2002).

TABLE 4.3
Recommended calcium intakes based on data from North America and Western Europe and theoretical calcium allowances based on an animal protein intake of 20–40 g/day

	Recommended intake (mg/day)	
	Based on data from North America and Western Europe	Theoretical calcium allowances based on an animal protein intake of 20–40 g/day
Infants and children		
0–6 months		
Breastfed	300	300
Fed cow milk	400	400
7–12 months	400	450
1–3 years	500	500
4–6 years	600	550
7–9 years	700	700
Adolescents		
10–18 years	1 300[a]	1 000[a]
Adults		
Females		
19 years to menopause	1 000	750
Postmenopause	1 300	800
Males		
19–65 years	1 000	750
65+ years	1 300	800
Pregnant women (last trimester)	***1 200***	***800***
Lactating women	***1 000***	***750***

[a] Particularly during the growth spurt.
Source: FAO and WHO, 2002.

The importance of dietary sources of vitamin D depends on what extent the skin is exposed to ultraviolet light (UVB), which is determined by latitude and season, as well as age and skin colour. The current recommended intake of dietary vitamin D ranges from 5 µg/day for infants, children, adolescents, adults aged 19–50 years and pregnant and lactating women to 15 µg/day for adults more than 65 years old (FAO and WHO, 2002).

Protein

Protein comprises half of the volume of bone. Bone can be considered a protein matrix, within which calcium (and other mineral) salts are deposited. Many epidemiological studies have found a positive relationship between protein intake and bone mass or density, and some studies suggest an inverse association between

protein intake and hip fracture (Kerstetter, Kenny and Insogna, 2011). However, there is much debate on the effect of protein on calcium absorption and status (Theobald, 2005). Studies using purified protein or protein hydrolysates have consistently shown a 1 mg rise in urinary calcium excretion for each 1 g of ingested protein (Weaver, Proulx and Heaney, 1999; Rafferty and Heaney, 2008). Proposed mechanisms include the effect of the acid load contained in animal proteins (which may be neutralized by the body drawing calcium from the bones) and complexing of calcium in the renal tubules by sulphates and phosphates released by protein metabolism (see FAO and WHO, 2002 and references therein). However, when protein is ingested as meat and/or dairy, the urinary loss of calcium has been reported to be less pronounced (Kerstetter and Allen, 1989). It has been suggested that the effect of protein intake on urinary calcium levels may be countered by the hypocalciuric effect (decreasing of urinary calcium losses) of phosphorus and potassium present in meat and dairy foods (Whiting *et al.,* 1997, and Heaney and Recker, 1982, both cited in Rafferty and Heaney, 2008). A summary by Roughead (2003) on the topic stresses the importance of this distinction between purified and common dietary protein sources, because the latter contain a substantial amount of phosphorus, which blunts the calciuric effect observed with purified proteins.

Despite the effects on urinary calcium losses, high protein intakes have been found to enhance calcium absorption, especially when the calcium content of the diet was limiting (600–800 mg/day) (Kerstetter, O'Brien and Insogna, 1998; Kerstetter, Kenny and Insogna, 2011). Dawson-Hughes (2003) reported that the impact of dietary protein on the skeleton appears to be favourable in older subjects who are meeting their dietary calcium requirements but not in those with lower calcium intakes. Other authors have highlighted that it is important to consider these effects in all stages of the life cycle and not just in the elderly population (Roughead, 2003; Spence and Weaver, 2003). In a recent review of the topic Kerstetter, Kenny and Insogna (2011) state that "Recent epidemiological, isotopic and meta-analysis studies suggest that dietary protein works synergistically with calcium to improve calcium retention and bone metabolism. The recommendation to intentionally restrict dietary protein to improve bone health is unwarranted, and potentially even dangerous to those individuals who consume inadequate protein".

Exercise can boost the benefits of good nutrition to growing bone, especially during growth (Bass *et al*., 2007; Specker and Vukovich, 2007; Welch *et al*., 2008; Nikander *et al.,* 2010): bone strength is increased with exercise, but sufficient calcium is necessary for increasing bone mass. Exercise helps to prevent bone loss only if calcium intake is greater than 1 000 mg/day, i.e. when there is sufficient calcium intake (Specker and Vukovich, 2007).

4.4.3 Milk and dairy foods and bone health

The mineral profiles in milk and bones have much in common. With the exception of small fish that are eaten whole, including the bones, few foods naturally contain as much calcium as milk (Weaver, Proulx and Heaney, 1999; Theobald, 2005). Calcium in milk has a high bioavailability, similar to calcium carbonate, which is readily absorbed (Theobald, 2005). Although many green leafy vegetables such as spinach are rich in calcium, they also contain oxalate, which reduces the calcium availability. Calcium availability is greater in plant foods such as broccoli, sweet potatoes, kale

and bok choy that contain smaller amounts of oxalic acid than in other plant foods (Fishbein, 2004, cited in Theobald, 2005). However, although soybeans contain large quantities of oxalates and phytates, the calcium they contain is still bioavailable (30–40 percent absorbed) (Heaney *et al*, 1991, cited in Theobald, 2005). Milk is the major source of vitamin D in the diet in countries where milk is fortified with this vitamin, e.g. the United States and Canada (USDA and USDHHS, 2010). Dairy foods are also a source of dietary protein. Analyses of food sources of calcium, vitamin D, protein, phosphorus and potassium in Americans reveal milk to be the number one single food contributor of most of these bone-related nutrients (Rafferty and Heaney, 2008).

The benefits to bone health of including dairy products in the diet or risks of excluding dairy products vary with the life stage. The relationship between milk products and bone mineral content and bone mineral density (BMD) was reviewed by US Department of Health and Human Services (USDHHS) and US Department of Agriculture (USDA) (2005), which found that milk, foods fortified with dairy calcium and calcium supplements all had comparable effects, increasing skeletal mass in younger subjects and reducing loss of skeletal mass in older subjects. However, skeletal benefits of dairy calcium may persist longer than those derived from calcium supplements (USDHHS and USDA, 2005).

A recent meta-analysis of 21 RCTs of calcium/dairy in children found no significant differences in total body bone mineral content between groups supplemented with dairy or calcium and comparison (control) groups. However, increased dietary calcium/dairy products, with and without vitamin D, significantly increased total body and lumbar spine bone mineral content in children with low dietary calcium intakes (450–746 mg/day) at baseline (Huncharek, Muscat and Kupelnick, 2008). In adolescents, controlled feeding studies with a range of calcium intakes show that dietary calcium explains 12–22 percent of the variation in skeletal calcium acquisition in girls and boys (Braun *et al.*, 2007; Hill *et al*., 2008). In adolescent girls, BMD has been shown to increase by up to 10 percent when 700 mg of supplemental calcium was provided in the form of dairy foods, compared with an increase of 1–5 percent when the same quantity of calcium was provided as a calcium supplement, suggesting that supplementation with dairy foods has a greater effect on bone health than do calcium supplements (Kerstetter, 1995).

Some of the benefit of increased calcium intake is transient and the gain in BMD is lost once calcium supplementation is discontinued (see references cited in Kalkwarf, Khoury, and Lanphear, 2003 and Section 4.4.5). Most RCTs have been one to two years in duration. However, a seven-year intervention study (Matkovic *et al*., 2005)[24] found that calcium supplementation (about 670 mg/day beyond a habitual dietary calcium intake of about 830 mg/day, giving a total calcium intake of about 1 500 mg/day) affected BMD during the pubertal growth spurt but had a diminishing effect thereafter because of the catch-up phenomenon in bone mineral accretion. By young adulthood, significant effects of calcium supplementation were present at metacarpals and at the proximal forearm in subjects who had better calcium com-

[24] Note, however, that only 51 percent of the subjects completed the seven-year trial.

pliance and in subjects who developed larger body frames (Matkovic *et al*., 2005). In another study, gain in bone mineral mass in prepubertal girls was followed up three to five years after discontinuation of calcium supplementation with calcium phosphate extracted from milk incorporated in various foods, which provided on average a calcium supplement of about 850 mg/day (Bonjour *et al.*, 2001). The authors concluded that this form of calcium phosphate taken during the prepubertal period can modify the trajectory of bone mass growth and cause a long-standing increase in bone mass accrual that lasts beyond the end of supplementation. In a two-year RCT, early pubertal girls receiving 1 g calcium from cheese had greater thickness of the cortical shell of the tibia than girls receiving the same amount of calcium from calcium carbonate or who received a placebo (Cheng *et al*., 2005). Based on these studies, Weaver (2008) concluded that advantage in bone gains due to intervention generally disappeared when calcium supplements were used, but not when the intervention was dairy.

Although bones may be more responsive to lifestyle choices in young people rather than later on in life, a meta-analysis showed that in premenopausal women of 18–50 years old a calcium intake of 1 000 mg/day or more was positively associated with bone mass (Welten *et al*., 1995). Consuming extra dairy products for three years increased calcium intake to an average of 810–1 572 mg/day, reduced vertebral BMD loss in premenopausal women (Baran *et al*., 1990). Dairy product consumption may have particular protective effects on women taking oral contraceptives (OC). In young OC users aged 18–30 years with a habitual calcium intake of less than 800 mg/day, increasing calcium intake to 1 000–1 100 mg/day or 1 200–1 300 mg/day) using dairy products (with an emphasis on non- and low-fat milk) protected against loss of hip and spine BMD (Teegarden *et al*., 2005). The authors speculate that an increase in calcium absorption mediated by an increase in calcitriol (1,25-dihydroxyvitamin D) levels may explain the positive response in bone accrual noted in OC users after dairy product intervention compared with non-OC users.

Most RCTs in older adults use calcium and vitamin D supplements rather than dairy products (Recker and Heaney, 1985; Elders *et al*., 1994). In one trial involving postmenopausal women that did use dairy products, adding 24 oz. of milk per day (giving a mean calcium intake during milk supplementation of 1 471 mg/day) suppressed bone turnover and improved calcium absorption resulting in an improvement in calcium balance (Recker and Heaney, 1985). Few RCTs of either dairy or calcium supplementation target younger adults.

Not all studies show an increase in BMD with calcium or dairy products: an analysis of the NHANES III data looked at the relative importance of dietary calcium intake and 25-hydroxyvitamin D (25(OH)D) serum concentrations with respect to total hip BMD among 9 961 individuals of 20 years of age or older (Bischoff-Ferrari *et al.*, 2009). This study found that calcium intake was not associated with BMD in adults of any age or gender who had an adequate vitamin D intake (serum 25(OH) D concentrations of greater than 50 nM). According to the authors, an advantage of the cross-sectional design of this study is that this is more likely to represent the long-term effects of calcium intake and 25(OH)D serum concentrations than would a short-term intervention.

4.4.4 Bone-remodelling transient

The bone remodelling transient is a temporary alteration in the balance between bone formation and bone resorption brought about by any factor (e.g. drugs, hormones or nutrients that alter either secretion of parathyroid hormone[25] or its action on bone) that affects bone remodelling (Heaney, 2001). According to Heaney (2001), because the remodelling activity is spread out over several months (several weeks in growing children, approximately three months in young adults and 6–18 months in older adults), nutritional interventions that alter remodelling produce a temporary phase lag between the normally coupled destructive and constructive components of the bone-remodelling process. This phase lag, when observed as an external balance or a dual-energy X-ray absorptiometry time course (commonly used to measure BMD), is the remodelling transient. Steady-state effects of any given nutrient intake can only be ascertained by measurements made after the transient has passed. The significance of the transient for nutritional interventions is both that early effects will always be misleading and that one can draw no inference whatsoever about the new steady state from what one observes during the transient phase (Heaney, 2001).

4.4.5 Limitations of studies using bone mineral density as an end point

BMD is used to define peak bone mass in young adults and is generally accepted to be a strong predictor of fractures in the elderly (see Bischoff-Ferrari *et al*., 2007). Bone mineral content in adults at any time is dependent on peak bone density achieved during development and subsequent bone loss; therefore, low BMD can result from poor bone accretion, accelerated bone loss or both (see Small, 2005 and references therein). BMD is often used as a surrogate measure of efficacy in clinical trials of osteoporosis therapies because even though studies with fracture incidence as a primary end point provide the most meaningful assessment, these trials typically require large numbers of patients and often take at least three years to generate sufficient data (Small, 2005). Although the majority of clinical trials with calcium or dairy product supplementation in children and adolescents that have been completed to date show a positive effect of intervention on bone mass, they are generally too short (one to three years) to address the question of whether it is the temporary adaptation of bone tissue to the alteration in calcium intake that leads to peak bone mass (Matkovic *et al*., 2005). The increase in bone mass observed in those short-term studies could be explained to a large extent by the bone-remodelling transient (see "Bone-remodelling transient", above). However, to conduct controlled feeding trials for sufficiently long periods for bone properties to change may not be practical except for animal studies (Weaver, 2008).

4.4.6 Osteoporosis

Osteoporosis is a condition of low bone mass with increased risk of fracture. Bones can get to that state through acquiring low peak bone mass during growth and/or through accelerated bone loss later in life as depicted in Figure 4.1. Worldwide

[25] Parathyroid hormone (PTH) regulates the quantity of remodeling activity.

variation in the incidence and prevalence of osteoporosis is difficult to determine because of problems with definition and diagnosis; the most useful way of comparing osteoporosis prevalence between populations is to use fracture rates in older people (WHO and FAO, 2003). Since osteoporosis is usually not life-threatening, quantitative data from developing countries are scarce (WHO and FAO, 2003). However, the consensus is that rates are many times higher in affluent developed countries than in sub-Saharan Africa and Asia. Osteoporosis is most common in Caucasian women living in temperate climates and least common in Africans (WHO and FAO, 2003).

Diet appears to have only a moderate relationship to osteoporosis, but calcium and vitamin D are both important, at least in older populations (WHO and FAO, 2003). Diets low in dairy products have been associated with increased risk of osteoporosis: bone resorption rates increased after just six weeks of an intervention designed to protect heart health by increasing fruit, vegetable and grain consumption while decreasing meat and dairy consumption (which recorded significant decreases in dairy servings per day and calcium and vitamin D from food) (Merrill and Aldana, 2009). A meta-analysis of nine studies reported lower BMD of the spine and hip in vegans than in those who consume milk (Ho-Pham, Nguyen, and Nguyen, 2009). Retrospective studies show that low milk consumption (less than one serving of milk/week) in childhood was associated with a doubling of hip fracture in American postmenopausal women, independent of current milk or calcium intake (Kalkwarf, Khoury, and Lanphear, 2003). However, no association was found between adolescent milk intake and the risk of osteoporotic fractures in these women. Higher calcium intakes throughout life (more than 800 mg/day) were found to significantly reduce the odds of osteoporosis defined by BMD by 25 percent in relatively healthy postmenopausal Caucasian women, as did higher current calcium and vitamin D intakes (Nieves *et al*., 2008). However, calcium and vitamin D intake did not significantly reduce the odds of any fracture. The authors ascribe a number of different reasons for this result, including insufficient power (despite large sample of 76 507 and 2 056 new fractures in three years, there were only 337 hip fractures), the multifactorial etiology of falls and fracture or the need for even higher levels of vitamin D or calcium in postmenopausal women (Nieves *et al*., 2008). Regular consumption of cheese and milk as well as chicken, egg, fruit and tea was protective against osteoporosis risk in Iranian women (Keramet *et al*., 2008).

Milk avoidance is also associated with increased risk of fracture in children (Goulding *et al*., 2004; Konstantynowicz *et al*., 2007). A milk-free diet (to avoid cow-milk allergy) has been associated with increased fracture risk in girls (Konstantynowicz *et al*., 2007), although the authors reported that it is unclear if this association is due to the illness, calcium deficit or a deficit in other milk nutrients. Based on their results, the authors concluded that the contribution of milk-free diet to fracture liability among children and adolescents is modest. In another study, 50 children (3–13 years) who had avoided drinking cow milk for prolonged periods were compared with those in a birth cohort of more than 1 000 children from the same city (Goulding *et al*., 2004). Children who avoided milk did not use calcium-rich food substitutes appropriately and had low dietary calcium intakes and low BMD values, and many were overweight. Significantly more of the milk avoiders experienced more total fractures than the birth cohort population, all of the frac-

tures occurring before puberty, leading the authors to conclude that young children avoiding milk are prone to fracture.

Results of meta-analysis of trials studying the effects of calcium with or without vitamin D on fracture prevention are mixed, depending on exclusion criteria, dose, and baseline age and calcium and vitamin D status (Tang *et al*., 2007; Bischoff-Ferrari *et al.,* 2007; Boonen *et al*., 2007). Tang *et al.* (2007) found that in trials that reported fracture as an outcome (17 trials, n=52 625), treatment was associated with a 12 percent risk reduction in fractures of all types (risk ratio = 0.88, 95 percent CI: 0.83–0.95; *P*=0.0004). The reduction in fracture risk was significantly greater (24 percent) in trials in which the compliance rate was high (*P*<0.0001). The treatment effect was greater with calcium doses of 1 200 mg or more than with doses of less than 1 200 mg (0.80 vs 0.94; *P*=0.006) and with vitamin D doses of 800 IU or more than with doses of less than 800 IU (0.84 vs 0.87; *P*=0.03). Boonen *et al*. (2007) found that for six RCTs (45 509 patients) of vitamin D with calcium supplementation, the pooled relative risk (RR) for hip fracture was 0.82 (95 percent CI: 0.71–0.94), with results suggesting that oral vitamin D reduces the risk of hip fractures only when calcium supplementation is added. However, on the basis of four RCTs with separate results for hip fracture (6 504 subjects, predominantly postmenopausal women, with 139 hip fractures), Bischoff-Ferrari *et al*. (2007) found that there was a significant increase in risk of hip fractures (pooled RR between calcium and placebo 1.64 [95 percent CI: 1.02–2.64]) when calcium supplementation between 800 and 1 200 mg/day was compared with placebo. For nonvertebral fractures there was a neutral effect in the RCTs (Bischoff-Ferrari *et al*., 2007). Based on a meta-analysis of pooled prospective studies, the same study found that calcium intake is not significantly associated with hip fracture risk in men and women (Bischoff-Ferrari *et al*., 2007). A meta-analysis of prospective cohort studies that looked at milk intake also concluded that there is no overall association between milk intake and hip fracture risk in women, while in men a possible benefit of higher milk intake could not be excluded, albeit based on limited data (Bischoff-Ferrari *et al.,* 2011).

The current evidence is that milk-product intervention in postmenopausal women and older men who have habitually low calcium intakes protects against bone loss (Lau *et al.*, 2001; Chee *et al.*, 2003; Daly, Bass and Nowson, 2006). A generalization from the literature may be that we need adequate supplies of both vitamin D and calcium to obtain significant reductions in nonvertebral fractures (especially hip fractures), and that those effects may be seen only in people who have insufficient vitamin D or calcium (or both) (Nieves and Lindsay, 2007). In addition, people need to consume an overall healthy diet that meets all nutrient requirements. WHO and FAO (2003) concluded that increases in dietary vitamin D and calcium in the older populations can decrease fracture risk in countries with high fracture incidence. Other lifestyle recommendations included to increase physical activity (particularly activities that maintain or increase muscle strength, coordination and balance as important determinants of propensity for falling, and regular lifetime weight-bearing activities, which can increase PBM in youth and help to maintain bone mass in later life); reduce sodium intake; increase consumption of fruits and vegetables; maintain a healthy body weight; avoid smoking; and to limit alcohol intake.

4.4.7 Calcium-deficiency rickets

Rickets is a progressive disease that begins with hypocalcemia and progresses to low mineralization of the growth plate of growing bones. The classic clinical symptom is deformity (bowing) of the arms and legs. Severe rickets is associated with deformities of the chest. Nutritional rickets may be caused by deficiency of either vitamin D or calcium, or more often by a combination of both (Pettifor, 2008). Vitamin-D-deficiency rickets is most prevalent within the first 18 months of life (Thacher *et al*., 2006a), and is more common in countries lying at high latitudes both north and south of the equator (Pettifor, 2008). It can also occur when vitamin D is in the normal range but dietary calcium is very low (less than 300 mg/day). Calcium deficiency depletes vitamin D status (measured by the amount of the inactive form) as conversion of vitamin D to its active form calcitriol is accelerated (Thacher *et al*., 2006b). Calcium- and/or vitamin-D-deficiency rickets have been reported in young children in 59 countries (Thacher *et al*., 2006a). In Africa and some parts of tropical Asia, calcium deficiency is the major cause of rickets, typically occurring after weaning and after the second year of life (Thacher *et al*., 2006a). High-fibre, low-calcium diets, common in these countries, can also increase clearance rates of vitamin D (Batchelor and Compston, 1983). Calcium supplementation (between 350 and 1 000 mg/day) without vitamin D has been reported to heal rickets in Nigeria (Craviari *et al*., 2008).

Although rickets had been almost eradicated in the twentieth century in many developed countries, a recent resurgence of the disease has been recorded in a number of developed countries. An increased risk of rickets has been recorded among the older children and adolescents in communities of recent immigrants in these countries, indicating that the combined effect of low dietary calcium intake and vitamin D deficiency may be involved, as their diets are typically low in calcium and high in phytates (Pettifor, 2008). The re-emergence of rickets has also been reported in Kenya (Bwibo and Neumann, 2003). The identified risk factors included: a low intake of milk (hence of calcium and phosphorus), no intake of ocean fish (hence a low vitamin D intake) and perhaps reduced exposure to sunshine and ultraviolet light. The lack of milk in the diet was highlighted as a major factor by the authors, and provision of milk supplements and vitamin D_3 for one month led to a noticeable regression of rickets in affected children (Bwibo and Neumann, 2003).

Minimal dairy intake is often a common characteristic associated with rickets. Rickets is not a result of impaired calcium absorption efficiency (Graff *et al*., 2004), nor was calcium absorption efficiency improved with vitamin D supplementation in Nigerian children (Thacher *et al*., 2009). Fischer, Thacher and Pettifor (2008) call for more research before widespread vitamin D supplementation is advocated to address rickets because the complex etiology is still being clarified. The final common pathway in the pathogenesis of rickets that has been suggested is an inability to meet the calcium needs of the growing skeleton, whether from vitamin D deficiency in the face of good calcium intake or from dietary calcium deficiency in the face of vitamin D sufficiency (Pettifor, 2008). Ideally, nutritional rickets would be prevented by ensuring all children receive adequate amounts of both vitamin D and calcium (Thacher *et al.,* 2006a, 2006b).

4.4.8 Summary

The main dietary factors that affect bone mass are calcium and vitamin D, while other nutrients such as potassium, zinc, vitamins A, C and K, protein and energy also contribute. Few other foods naturally contain as much calcium as milk. Calcium in milk also has high bioavailability. Calcium and vitamin D are interdependent. The current recommended intake of vitamin D for ranges from 5 to 15 µg/day (FAO and WHO, 2002). FAO and WHO (2002) also recommended a calcium intake of 1 300 mg/day for adults more than 65 years old in countries with high animal protein consumption, and 800 mg/day for adults more than 65 years old in countries with low animal protein consumption (20–40 g/person per day). However, this was based on calcium balance studies of average duration 90 days, not clinical outcomes; the time-scale of such calcium balance studies may still be too short for true bone balance, and may merely reflect changes in the bone remodeling transient rather than reflecting long-term calcium balance. The Expert Consultation also highlighted the "calcium paradox", i.e. that hip fracture rates are higher in developed countries where calcium intake is higher than in developing countries where calcium intake is lower, and suggested that it may be related to protein intake, vitamin D status or sodium intake. Recognizing that requirements may vary, for countries with low consumption of animal protein (20–40 g/day), a lower recommendation of 800 mg/day for adults more than 65 years old was proposed. A subsequent WHO/FAO expert consultation (WHO and FAO, 2003) concluded that there is convincing evidence that sufficient intake of vitamin D and calcium together reduces the risk of osteoporotic fracture in older people. After considering the strength of the evidence with fracture as an end point (rather than BMD), the report recommended a minimum daily intake of 400–500 mg of calcium to prevent osteoporosis in older people in countries with a high fracture incidence (WHO and FAO, 2003). The report cautioned that before recommending increased calcium intake in countries with low fracture incidence, the interaction between calcium intake and physical activity, sun exposure and intake of other dietary components and protective phytonutrients needs to be considered.

Many epidemiological studies have found a positive relationship between protein intake and bone mass or density, and some studies have reported an inverse association between protein intake and hip fracture. High protein intakes have also been found to enhance calcium absorption. Protein is a major bulk constituent of bone and must be regularly supplied by the diet; milk and other dairy foods are a source of dietary protein. Some dairy products also provide other nutrients that support bone health, such as potassium, zinc and vitamin A, and if fortified, vitamin D. Exercise has been shown to help prevent bone loss only if calcium intake is greater than 1 000 mg/day. However, these conclusions are based on short-term studies, and there is currently no evidence to support such an interaction in relation to risk of fractures.

Overall, genetics are believed to control 60–80 percent of differences in bone mass and environmental factors, such as diet and physical activity, 20–40 percent. Increased calcium intake suppresses bone resorption relative to bone formation, resulting in greater calcium balance. The impact of dietary dairy products on bone health depends on life stage. In adolescents, dietary calcium explains 12–22 percent of the variation in skeletal calcium acquisition. Dairy product consumption and cal-

cium intake can also have a positive effect on bone mass in premenopausal women and reduce bone mineral density loss. In older adults, the effectiveness of dairy/calcium supplementation depends on various factors. BMD is used to define peak bone mass in young adults and it is generally accepted to be a strong predictor of fractures in the elderly. One limitation of BMD trials is that although a short-term increase in BMD may be seen, effects may be transitory. Although the majority of clinical trials with calcium or dairy-product supplementation in children and adolescents show a positive effect of intervention on bone mass, they are generally too short to address the question of whether it is the adaptation of bone tissue to nutritional challenge that leads to peak bone mass. There is some evidence to suggest that advantages in bone gains due to interventions may remain when the intervention is discontinued if the intervention is dairy.

Osteoporosis is a condition of low bone mass with increased risk of fracture. According to the WHO and FAO (2003), diet appears to have only a moderate relationship to osteoporosis, but calcium and vitamin D are both important, at least in older populations. Diets with low dairy product intake have been associated with increased risk of osteoporosis. The results from two studies suggest that milk avoidance is associated with increased risk of fracture in children. Milk consumption in childhood may also protect against the risk of osteoporotic fractures in postmenopausal women. However, milk consumption during adult life does not appear to be associated with reduced risk of fracture. Milk-product intervention in postmenopausal women and older men who have habitually low calcium intakes appears to protect against bone loss. Meta-analysis of RCTs of calcium with or without vitamin D show mixed results for fracture prevention: some studies suggest an improvement in fracture outcome with calcium (Boonen *et al*., 2007; Tang *et al*., 2007), some show no effect (Bischoff-Ferrari *et al*., 2007, for nonvertebral fractures) and some even show an increase in fractures (Bischoff-Ferrari *et al*., 2007, for hip fractures). Meta-analyses of pooled prospective epidemiologic studies suggest that calcium intake is not significantly associated with hip fracture risk in men and women (Bischoff-Ferrari *et al*., 2007, 2011), although a possible benefit for men of a higher milk intake could not be excluded (Bischoff-Ferrari *et al.,* 2011). Most of the evidence suggests that adequate supplies of both vitamin D and calcium are necessary to see significant reductions in nonvertebral fractures, and those effects may be seen only in people who have too little vitamin D or calcium (or both) in their diets. Other lifestyle recommendations for reducing osteoporosis include increasing physical activity; reducing sodium intake; increasing consumption of fruits and vegetables; maintaining a healthy body weight; avoiding smoking; and limiting alcohol intake. There is no satisfactorily answer to the question behind the "calcium paradox", i.e. why the vast majority of the world's population consumes 500 mg of calcium or less per day and little or no dairy products and yet still has low fracture rates. An overall healthy lifestyle and diet that includes adequate calcium and vitamin D is perhaps the most appropriate recommendation. And we need to keep in mind, as aptly stated by Nieves and Lindsay (2007), "Bone is not just calcium, and calcium does not function in isolation".

Calcium and/or vitamin D-deficient rickets have been reported in young children in 59 countries. Nutritional rickets may be caused by either vitamin D or calcium deficiency, or more often, by a variable combination of both. The final common

pathway in the pathogenesis may be an inability to meet the calcium needs of the growing skeleton, whether from vitamin D deficiency in the face of a good calcium intake, or from dietary calcium lack in the face of vitamin D sufficiency. In Africa and some parts of tropical Asia calcium deficiency is the major cause of rickets, typically occurring after weaning and often after the second year of life (Thacher *et al*., 2006b).

4.5 DIETARY DAIRY AND ORAL HEALTH

Dental disease is the most common cause of tooth loss in developed countries (USDHHS, 2000). Tooth decay is an increasing problem in developing countries as diets change to include more sweet and processed foods (Liljemark and Bloomquist, 1996, cited in Aimutis, 2004).

Since the late 1950s, milk was believed to have a protective effect on tooth enamel (Shaw, Ensfied and Wollman, 1959; Jenkins and Ferguson, 1966). Milk has been suggested to have a protective effect against sugar when consumed together (Bowen and Pearson, 2003, cited in Johansson and Lif Holgerson, 2011). The anticariogenic effect of dairy products has been attributed to constituents such as calcium, phosphate and casein (Aimutis, 2004). Bioactive components in milk may also reduce dental caries by changing the microbial population of dental plaque, i.e. by inhibition of adhesion of cariogenic streptococcal bacteria and establishment of less cariogenic species such as oral actinomyces (Aimutis, 2004; Johansson and Lif Holgerson, 2011). Animal studies have demonstrated reductions in dental caries when soluble calcium and phosphate salts were added to foods (Bowen, 1971; Grenby and Bull, 1975; van der Hoeven, 1985). Epidemiologic studies have shown that children and adults with higher concentrations of calcium and phosphate in their dental plaque had a lower incidence of dental caries (Ashley and Wilson, 1977; Schamschula *et al*., 1978). When caseinophosphopeptides from milk react with calcium and phosphate at the tooth surface they produce colloidal amorphous calcium phosphate complexes which promote remineralization of enamel in humans (Aimutis, 2004).

In an in vitro study, yoghurt containing casein phosphopeptides prevented demineralization of tooth enamel and enhanced its remineralization (Ferrazzano *et al*., 2008). A Swedish study found that children who never ate cheese or ate it only once in the five-day period recorded had an average of 1.5 surfaces affected by caries, whereas those who ate cheese five times or more in the five-day period (i.e. on average at least once a day) were caries free (Öhlund *et al*., 2007). The number of caries did not correlate with intake frequency or total intake of any other food studied, which included biscuits, cakes, sweet rolls, ice cream, fruit syrup, soft drinks, marmalade, jam, chocolate, candies and sugar (Öhlund *et al*., 2007). A similar study in Japan suggested that high intake of yoghurt may reduce the prevalence of dental caries in children but showed no association between caries and milk or cheese consumption (Tanaka, Miyake and Sasaki, 2010). The exact mechanism by which certain dairy products are anticariogenic is still unclear, but the current evidence suggests that consumption of these milk products can protect against dental caries (Johansson and Lif Holgerson, 2011). WHO and FAO (2003) reported that both hard cheese and milk probably decrease risk of dental caries, and that hard cheese also possibly decreases the risk of dental erosion.

4.6 DAIRY INTAKE, WEIGHT GAIN AND OBESITY DEVELOPMENT

The increasing incidence of overweight and obesity is a global public health concern (WHO, 2011a). WHO (2012c) estimates indicate that more than 1.4 billion people are overweight (body mass index [BMI] between 25 and 30 kg/m^2), 500 million of whom are obese (BMI 30 kg/m^2 or more). Adult obesity rates continue to increase and the WHO estimates that in many countries, including Argentina, Greece, the United Kingdom and the United States, a large percentage of the population will shift from the overweight category to the obese category between 2005 and 2015 (Dougkas *et al.*, 2011). Obesity is associated with increased mortality and risk of non-communicable chronic diseases such as CVD, diabetes, hypertension, certain cancers and osteoporosis (Shetty and Schmidhuber, 2011).

4.6.1 Dietary patterns and the risk of obesity

The aetiology of obesity is complex and the assessment of dietary patterns related to obesity has become increasingly popular in nutritional epidemiology (Jebb, 2007). Excess energy consumed over a sustained period can lead to obesity. However, certain dietary patterns are associated with a greater risk of obesity because of their high energy content. A study of the dietary patterns of 15 890 Mexican adults found that the patterns with the highest consumption of refined foods, sweets and animal products were associated with being overweight or obese (Flores *et al.*, 2010). Sichieri (2002) reported that a "Western diet", which included butter, margarine and soda, was associated with an increased risk of obesity in adults living in Rio de Janeiro. A cross-sectional study based in Mongolia (Dugee *et al.*, 2009) concluded that a traditional diet rich in whole milk, fats and oils, sugar and confectionery, yoghurt, kumis (fermented mare milk), horse meat and refined wheat products was associated with a greater risk of abdominal obesity than was a "healthy" diet with greater intake of whole grains, mixed vegetables and fruits. The healthy diet also included some dairy products, suggesting that consumption of moderate quantities[26] of yoghurt and kumis does not increase the risk of obesity (Dugee *et al.*, 2009). Using data from the Danish Diet Cancer and Health Study, Halkjaer *et al.*, (2009) reported that, of 21 food and beverage groups examined (including high-fat and low-fat dairy products), only snack foods (chocolates, sweets, liquorice, fruit, gum, toffee, pork rind, potato crisps and French fries) were significantly associated with subsequent five-year differences in waist circumference. Romaguera *et al.*, (2011) analysed data from 48 631 men and women from five countries participating in the European Prospective Investigation into Cancer and Nutrition (EPIC) study and concluded that a dietary pattern characterized by a high consumption of fruits and dairy products and a low consumption of soft drinks, white bread, processed meat and margarine may help to prevent abdominal fat accumulation.

The recent expert consultation on fats and fatty acids (FAO and WHO, 2010) reported that "a general recommendation is to follow a dietary pattern predominantly based on whole foods (i.e. fruits and vegetables, whole grains, nuts, seeds,

[26] Factor loading matrices were calculated for the three dietary patterns. The "traditional" and "healthy" pattern had factor loading matrices of 0.519 and 0.225, respectively, for yoghurt and kumis.

legumes, other dietary fibre sources, seafood rich in long-chain PUFAs) with a relatively lower intake of energy dense processed and fried foods, and sugar sweetened beverages; and to avoid consumption of large portion sizes. Moderate consumption of dairy products and lean meats and poultry can also be an important part of recommended food-based dietary guidelines. Maintaining recommended dietary patterns, appropriate energy intake and adequate physical activity levels are critical to prevent unhealthy weight levels (i.e. overweight and obesity)" (FAO and WHO, 2010).

4.6.2 Association between dairy intake and weight status

Nutritional studies examined use a wide range of outcome and exposure measures making it very difficult to compare results of studies. Sample sizes and the type of dairy analysed vary and some studies do not control for energy restriction. If adjustments are not made for total energy intake, the energy from dairy food in excess of total daily energy requirement could confound the impact of dairy on obesity risk. Additionally, direct comparison of prevalence rates of overweight and obesity is difficult as different countries use different methodology, criteria and growth references in classifying overweight and obesity.

FAO and WHO (2010) concluded that "there was convincing evidence that energy balance is critical to maintaining healthy body weight and ensuring optimal nutrient intakes, regardless of macronutrient distribution of energy as percent total fat and percent total carbohydrates". As it was not possible "to determine at a probable or convincing level the causal relationship of excess energy and unhealthy weight gain", the current recommendation for a maximum intake level of 30–35 percent of energy from fat was considered prudent. "There was agreement among the experts that in populations with inadequate total energy intake, such as seen in many developing regions, dietary fats are an important macronutrient to increase energy intake to more appropriate levels" (FAO and WHO, 2010).

Epidemiological studies on dairy and obesity can be broadly categorized as those that assess the positive effect of dairy on weight gain and those that examine the protective role of dairy (particularly calcium) against weight gain. Louie *et al.* (2011) recently systematically reviewed prospective cohort studies that assessed the longitudinal relationship between dairy and obesity. Out of 19 studies, eight (three involving children and five involving adults) showed a protective association of dairy intake against weight gain, seven found no impact on weight, one reported a significant protective association among overweight men, one reported an increased risk of weight gain among children with a high milk intake, and two studies reported both an increased and decreased risk of weight gain, depending on the dairy food type. Low-fat products were not found to be any more beneficial to weight status than whole milk or full-fat products. Thus, although there is some indication of a protective effect of dairy on weight, it is not conclusive, suggesting that if such an effect exists the magnitude is likely to be small (Louie *et al.*, 2011). Additionally, a recent systematic review of 16 studies reported that "the observational evidence does not support the hypothesis that dairy fat or high fat dairy foods contribute to obesity and suggests that high fat dairy consumption within typical dietary patterns is inversely associated with obesity risk" (Kratz, Baars and Guyenet, 2012).

In a study of 14 618 adults in the United States, Beydoun *et al.* (2008) found a positive association between cheese consumption and obesity and a negative

association between yoghurt and obesity, possibly due to the higher energy density in cheese compared with other dairy products. The lack of a relationship between milk or dairy-product intake and weight gain is also supported by Mozaffarian *et al.* (2011). This large-scale investigation involved three separate cohorts (Nurses' Health Study, Nurses' Health Study II and the Health Professionals Follow-up Study) totalling 120 877 women and men in the United States and examined the relationship between multiple lifestyle changes (diet, physical activity, television watching, alcohol use, sleep duration and cigarette smoking) and long-term weight gain. The authors assessed a range of dietary factors including fruits, vegetables, whole and refined grains, potatoes, potato crisps, whole-fat and low-fat dairy products, sugar-sweetened beverages, sweets and desserts, processed meats, unprocessed red meats and fried foods. They reported that "eating more or less of any one food or beverage may change the total amount of energy consumed, but the magnitude of associated weight gain varied for specific foods and beverages. The analysis showed relatively neutral associations between change in the consumption of most dairy foods and weight gains" (Mozaffarian *et al.*, 2011). All liquids except milk were positively associated with weight gain and no significant differences were observed for low-fat and skim milk versus whole-fat milk. Yoghurt consumption was associated with less weight gain in all three cohorts; however the mechanism for this finding is not clear (Mozaffarian *et al.*, 2011).

A recent systematic review of RCTs found that increased dairy intake without energy restriction may not lead to significant change in weight, whereas dairy consumption in energy-restricted diets result in a greater reduction of weight and fat mass and gain in lean body mass (Abargouei *et al.*, 2012). In controlled feeding studies in adults and adolescents, dairy did not affect energy balance (Van Loan *et al.*, 2011; Weaver *et al.*, 2011).

Dairy consumption and childhood obesity

Whether dairy consumption in childhood has an etiologic role in the development of obesity in later life is an open area of discussion (Moore *et al.*, 2006). IGF-1 levels may be indicative of risk of obesity as IGF-1 may be one of the factors involved in fat-cell formation. This is supported by some observations of high IGF-1 levels in obese children. However, not all clinical evidence supports this and normal concentrations of IGF-1 have also been reported in obese children (Hoppe, Mølgaard and Michaelsen, 2006). IGF-1 may further contribute to obesity development as it suppresses the secretion of growth hormone, which is related to lean body mass (Hoppe, Mølgaard and Michaelsen, 2006; Dougkas *et al.*, 2011). The impact of milk protein intake on body composition has not been fully elucidated. Intake of dairy protein in infancy may increase the risk of excess weight gain in childhood (Hoppe *et al.*, 2004; Gunther *et al.*, 2007). However, it is also important to consider that body weight includes fat, muscle and bone mass and the association between dairy protein and weight gain in children may be related to the increase in non-fat mass during growth and development (Cadogan *et al.*, 1997; Spence, Cifelli and Miller, 2011).

In a cohort study of 12 829 American children between the ages 9 and 14 years, Berkey *et al.* (2005) found that the BMI of children who drank more than three servings of milk per day increased more than that those who drank less milk as a

result of the additional energy intake. Fat intake (total or from dairy, vegetable or other source) was not significantly associated with weight gain after energy adjustment, suggesting that the most important predictor of weight change is total energy intake. Notably, dietary calcium and low-fat milk (skim and 1 percent milk) were also associated with weight gain. The effects of dietary calcium and milk appear to be explained by energy intake as the associations were attenuated when energy was adjusted (Berkey *et al*., 2005).

4.6.3 Dairy as part of a weight loss strategy

Calcium and 1,25-hydroxyvitamin D regulate lipid metabolism in adipose cells by stimulating fatty acid oxidation and suppressing lipogenesis. Studies also suggest that calcium may decrease fatty acid absorption and increase faecal fat losses (Caan *et al*., 2007). However, experimental data in this area are inconclusive. Few studies have investigated the effect of calcium on weight and these have tended to be of short duration with small sample sizes and results should be interpreted with caution (Theobald, 2005; Caan *et al*., 2007).

Cross-sectional epidemiological studies indicate that high dairy food intake can affect weight management, but prospective studies and randomized controlled intervention trials have yielded inconsistent results. Some clinical studies have shown that diets that include three servings of dairy foods per day may enhance body weight and/or fat loss and reduce abdominal fat compared with those that contain little or no dairy (Zemel *et al*., 2004; Zemel *et al*., 2005a, 2005b). However, this effect is generally seen in obese and overweight individuals when calories are moderately restricted and dairy/calcium intakes are increased from inadequate to adequate (Zemel *et al*., 2004; Zemel *et al*., 2005a, 2005b).

Tremblay and Gilbert (2011) reported that low dietary calcium is a risk factor for overweight and obesity and that calcium/dairy supplementation may accentuate the impact of a weight-reducing programme in obese people with a low calcium intake. However other studies refute any impact effect of calcium supplementation on weight loss, and some suggest that intakes of milk and dairy must surpass a threshold before beneficial effects on body weight are seen (Harvey-Berino *et al*., 2005; Ferland *et al*., 2011; Rosado *et al*., 2011). In a systematic review of the effects of calcium supplementation on body weight, Trowman *et al*. (2006) concluded that supplementation with calcium supplements or dairy products has no statistically significant association with a reduction in body weight. The Women's Health Initiative RCT of calcium and vitamin D supplements, which involved 36 282 postmenopausal women and lasted more than seven years, reported a minimal effect of calcium on weight, primarily in participants who had reported inadequate calcium intakes (Caan *et al*., 2007). The authors also remarked that the benefit of calcium on weight maintenance may be small, and may have been detected in this RCT only because of its large sample size. Using data from the prospective cohort Health Professionals Follow-up Study, Rajpathak *et al*. (2006) concluded that the data do not support the hypothesis that an increase in dairy or calcium intake is associated with lower long-term weight gain in men. Theobald (2005) states that "further research is required in this area to determine whether or not calcium plays a role in weight management and if so what the mechanisms may be. It is too early to promote weight-loss benefits of additional calcium" (Theobald, 2005).

Some studies suggest that moderately increasing protein intake, while controlling total energy intake may improve body composition and improve body-weight maintenance (Westerterp-Plantenga, 2003; Paddon-Jones *et al*., 2008; Abou-Samra *et al*., 2011). The potential positive outcomes associated with increased protein are thought to be due to lower energy intake associated with increased satiety and increased thermogenesis. Findings of studies of the impact of dairy proteins, whey and casein, on satiety are inconclusive (Abou-Samra *et al*., 2011). The effects of whey protein, such as reduction of short-term food intake and increased satiety have been mostly observed in short-term experiments when whey is consumed in much larger amounts than that found in usual serving sizes of dairy products (Luhovyy, Akhavan and Anderson, 2007). Inconsistencies in the studies may be attributed to the study design, subject sample or the different physical properties of the proteins used. Additionally, dairy proteins are consumed in food form (Anderson *et al*., 2011) and as such, "despite the suggestion of acute or transient benefits attributable to specific proteins, any such effect may be masked by the concomitant ingestion of a mixture of proteins and other macronutrients in a normal mixed diet" (Paddon-Jones *et al*., 2008).

There is a need for well-designed long-term intervention studies that clearly define the primary outcome (body-weight changes or measures in adiposity) to confirm if dairy products can increase weight loss and/or improve weight maintenance (Harvey-Berino *et al.*, 2005; Major *et al*., 2008; Van Loan, 2009; Zemel, 2009; Dougkas *et al*., 2011).

4.7 DAIRY INTAKE, METABOLIC SYNDROME AND TYPE 2 DIABETES

Metabolic syndrome (MetS) describes a cluster of metabolic abnormalities that are risk factors for CVD and type 2 diabetes mellitus (T2DM), including abdominal obesity, hypertension, elevated fasting glucose, elevated triglycerides and low high-density lipoprotein (HDL) cholesterol (Mokdad *et al*., 2001). Worldwide, 197 million people have impaired glucose tolerance due to obesity and MetS, and it is estimated that by 2025 this number will rise to 420 million (Hossain, Kawar and Nahas, 2007). Recommendations for preventing and managing MetS include reducing obesity, increasing physical activity and effecting dietary change[27] (Grundy *et al*., 2004). According to the International Diabetes Federation, primary management of MetS includes promoting healthy lifestyle with energy restriction (to achieve a 5–10 percent loss of body weight in the first year), moderate increases in physical activity, a reduction in total and saturated fat intake, increased fibre intake and reduced salt intake (Alberti, Zimmet and Shaw, 2006). In addition, whenever possible, a normal BMI and/or normal waist circumference should be a long-term target of lifestyle interventions. However, Feldeisen and Tucker (2007) suggest that a diet low in saturated fat (rather than low in total fat), trans fat and cholesterol, and a balanced carbohydrate intake rich in dietary fibre, fruit and vegetables, and inclusion of low-fat dairy products may be most beneficial for reducing the risk of the MetS.

[27] These recommended dietary guidelines include low intakes of saturated fats, trans fats and cholesterol; reduced consumption of simple sugars; and increased intakes of fruits, vegetables and whole grains.

Dietary patterns with higher dairy intake have been shown to be associated with reduced risk of some of the MetS components (Appel *et al*., 1997; Azadbakht *et al*., 2005; Tremblay and Gilbert, 2009). In a systematic review of observational evidence, Tremblay and Gilbert (2009) reported that the odds for developing MetS was 0.71 (95 percent CI: 0.57–0.89) for the highest dairy intake (3–4 servings per day) versus the lowest dairy intake (0.9–1.7 servings per day). Dairy consumption was also found to have favourable effects on blood pressure and obesigenic parameters, albeit the results were less consistent. Appel *et al*. (1997) showed that a combination of fruits, vegetables and low-fat dairy (the so-called "Dietary Approaches to Stop Hypertension (DASH) diet") resulted in the greatest reductions in blood pressure, whereas a fruit and vegetable diet that excluded dairy products was about half as effective. A DASH diet was also found to increase HDL cholesterol, lower triglycerides, lower blood pressure, promote weight loss and reduce fasting blood glucose in both men and women in Tehran as compared with the control diet (Azadbakht *et al*., 2005). In a French prospective study with a nine-year follow-up, Fumeron *et al*. (2011) reported that "dairy (except cheese) consumption and dietary calcium density were inversely associated with incident MetS and T2DM and all parameters were associated with lower diastolic blood pressure and triglycerides".

Although some studies suggest that consumption of dairy food may have a beneficial impact on the MetS components (Mensink, 2006; Pfeuffer and Schrezenmeir, 2007; Fumeron *et al*., 2011), Dietary Guidelines Advisory Committee (DGAC) (2010) concluded that there is limited evidence demonstrating that consumption of milk and dairy products is associated with reduced risk of MetS.[28] There is, however, moderate evidence showing an association between milk and dairy product consumption and lower incidence of T2DM in adults[29] (DGAC, 2010). A number of review studies have been published since the DGAC (2010) report. In a systematic review and meta-analysis involving five cohorts involving 184 454 participants, the relative risk for T2DM was estimated to be 15 percent lower in people who had a high milk intake[30] (Elwood *et al*., 2010). In another meta-analysis of seven cohort studies involving 328 029 participants, Tong *et al.* (2011) also found an inverse association between dairy consumption and T2DM, especially low-fat dairy (RR 0.82, 95 percent CI: 0.74–0.90) and yoghurt (RR 0.83, 95 percent CI: 0.74–0.93). Consumption of high-fat dairy foods and whole milk was not associated with the risk of T2DM. In a recent systematic review of dairy consumption and MetS involving 10 cross sectional studies (36 113 participants) and three prospective cohort studies (13 795 participants), Crichton *et al*. (2011) reported that the majority of studies

[28] The conclusion reached for the relationship between milk/milk products and MetS was based on one systematic review with meta-analysis (Elwood *et al.*, 2008), one prospective cohort study (Snijder *et al.*, 2008) and two cross-sectional studies (Ruidavets *et al*., 2007; Beydoun *et al.*, 2008).

[29] The conclusion reached for the relationship between milk/milk products and T2DM was based on the systematic review with the meta-analysis of four prospective studies on diabetes (Elwood *et al.*, 2008).

[30] Within the studies, the quantity of milk defined as high and low varied. Most of the studies used quartiles or quintiles of the distribution of intakes while other studies reported the occasion or frequency, for example two or more servings of dairy foods per week versus less than one serving per month.

suggest that consumption of dairy products reduces the risk of having MetS, but conclude that methodological differences, possible biases and other limitations in the studies prevent conclusions being drawn. Thus, overall, although more research is needed, there is emerging evidence that dairy product consumption may decrease risk of MetS and T2DM.

The mechanisms by which dairy products may affect T2DM and MetS are not yet clear. The effect of dairy consumption on T2DM may be mediated through calcium and vitamin D (Pittas *et al.,* 2007). Calcium intake may increase fat oxidation and suppress adipose tissue oxidative and inflammatory stress, while vitamin D may enhance the thermic effect of a meal and hence increase fat oxidation (see Tong *et al.,* 2011 and references therein). Other components in dairy products may also have a role in lowering the risk of T2DM (see Tong *et al.,* 2011 and references therein). For example, dairy protein may reduce the risk of overweight and high blood pressure, major risk factors for T2DM. Dairy proteins may increase satiety, which may reduce energy intake. Additionally the proteins are precursors of peptides that inhibit angiotensin-I-converting enzyme, which may reduce blood pressure. However these effects have been inconsistently reported in human studies (van Meijl, Vrolix and Mensink, 2008). Furthermore, the fatty acid trans-palmitoleate, which is obtained primarily from whole-fat dairy, has been associated with a lower incidence of diabetes (Mozaffarian *et al*., 2010). More research is needed to better understand the mechanisms involved and the relationship between dairy consumption and MetS and the risk of T2DM (Van Loan, 2009; Crichton *et al*., 2011).

4.8 DAIRY INTAKE AND CARDIOVASCULAR DISEASE

Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels and include CHD (disease of the blood vessels supplying the heart muscle); cerebrovascular disease (disease of the blood vessels supplying the brain); peripheral arterial disease (disease of blood vessels supplying the arms and legs); rheumatic heart disease (damage to the heart muscle and heart valves from rheumatic fever, caused by streptococcal bacteria); congenital heart disease (malformations of heart structure existing at birth); deep vein thrombosis and pulmonary embolism (blood clots in the leg veins, which can dislodge and move to the heart and lungs); and heart attacks and strokes (mainly caused by a blockage that prevents blood from flowing to the heart or brain) (WHO, 2012a). CVD kills 17 million people worldwide each year and is the world's number one cause of death (WHO, 2008). Many risk factors for CVD can be controlled; these include cigarette smoking, physical inactivity, high blood pressure (hypertension), elevated total and LDL blood cholesterol, reduced HDL cholesterol, elevated triglycerides and overweight/obesity (Krauss *et al*., 2000; Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults, 2001, Thom *et al*., 2006). Worldwide, raised blood pressure is estimated to cause 7.5 million deaths annually; raised blood pressure is a major risk factor for CHD and ischaemic and haemorrhagic stroke (WHO, 2012b).

Milk and dairy foods are most often linked to CVD risk/events on account of the milk fat, particularly the high content of SFA. Other nutrients in milk have also been implicated with CVD risk, such as protein (Bernstein *et al.,* 2010), lactose (Segall, 1994; Moss and Freed, 2003) and the high calcium-to-magnesium ratio (Moss and Freed, 2003). As milk fat and protein contents are genetically correlated (if the fat

content has not been artificially adjusted by processing – see Chapter 3, section on Lactation stage and milk composition), the milk protein-CVD hypothesis is not unreasonable (but only if the fat hypothesis is accepted). The lactose-hypothesis has been criticized as being based on unconvincing ecological data (Al-Delaimy, 2008). However, other nutrients in dairy foods such as calcium, monounsaturated fatty acids (MUFAs), PUFAs[31] and protein may modify risk factors for CHD (Gibson *et al*., 2009). Dairy foods are rich in calcium and two meta-analyses of RCTs have demonstrated that increased calcium intake appears to reduce high blood pressure (Bucher *et al.,* 1996, and Allender *et al.,* 1996, cited in Gibson *et al*., 2009). Potassium and dairy phosphorus have also recently been associated with antihypertensive effects (Soedamah-Muthu *et al.*, 2011).

4.8.1 Effects of dietary fat on cardiovascular disease

The recent FAO/WHO expert consultation on fats and fatty acids (FAO and WHO, 2010) concluded that that there is no probable or convincing evidence for significant effects of total dietary fats on CHD or cancer. Of primary concern and importance was the possible relationship between total dietary fat and body weight (overweight and obesity). The consultation recommended that 20–35 percent of energy in the diet should come from fat, with a minimum of 15 percent to ensure adequate consumption of total energy, essential fatty acids and fat-soluble vitamins.

The expert consultation concluded that individual SFAs have different effects on the concentration of plasma lipoprotein cholesterol fractions. For example, lauric (C12:0), myristic (C14:0) and palmitic acids (C16:0) increase LDL cholesterol whereas stearic acid (C18:0) has no effect. The report recommended that total intake of SFAs should not exceed 10 percent of total dietary energy, and SFAs should be replaced with n-3 and n-6 PUFAs, based on convincing evidence that this replacement can decrease the risk of CHD (FAO and WHO, 2010). The long-chain PUFAs alpha linolenic acid (C18:3 n-3), eicosapentanoic acid (C20:5 n-3) and decosahexaenoic acid (C22:6 n-3) can be part of a healthy diet contributing to the prevention of CHD (FAO and WHO, 2010). ASF including milk are sources of n-6 and n-3 FAs, although milk contains less than fish, meat, poultry and eggs (Michaelsen *et al*., 2011b). The expert panel also stated that there is convincing evidence that replacing SFAs (C12:0 to C16:0) with PUFAs reduces LDL-cholesterol concentration and the ratio of total cholesterol to HDL cholesterol. The expert panel noted that there is probable evidence that replacing SFAs with largely refined carbohydrates does not reduce CHD, and may even increase the risk of CHD and MetS. There was insufficient evidence for establishing relationships between MUFA consumption and CHD (FAO and WHO, 2010). The expert panel found convincing evidence that industrial TFA (iTFA) increases CHD risk factors and CHD events. The experts reported that the estimated average daily ruminant TFA (rTFA) (from the consumption of milk/dairy products and meat/meat products from ruminant sources such as cows, sheep and goats) is

[31] As noted in Chapter 3, cow milk contains only about 6 g PUFA/ 100 g total fatty acid.

low among adults in most countries, and the scientific evidence for health effects of these levels of rTFA consumption warrants only limited concern. A total TFA intake of less than one percent of dietary energy was recommended. A recent systematic review and meta-analysis of cohort studies (Bendsen *et al.,* 2011) supports the conclusions regarding iTFA and rTFA and risk of CVD.

Studies that have been published since the expert consultation are generally in agreement with the conclusions of the panel. For example, a recent review supports the conclusions relating to total fat and SFAs (Hooper *et al.,* 2011): there was moderate evidence to suggest that modification of dietary saturated fat content[32] and reduction of saturated fat intake (but not reduction of total fat) may reduce cardiovascular events overall by 14 percent (RR 0.86, 95 percent CI: 0.77–0.96, 65 508 participants). However, no significant evidence was found for concluding that dietary saturated fat is associated with an increased risk of CVD in another recent meta-analysis of prospective cohort studies (Siri-Tarino *et al*., 2010). The presumed beneficial effects of diets with reduced saturated fat for CVD risk may be dependent on a significant increase in polyunsaturated fat in the diet (Siri-Tarino *et al*., 2010). A large evidence base suggests that n-6 PUFAs reduce risk of CHD (Kris-Etherton, Fleming and Harris, 2010) by lowering LDL and total cholesterol levels. In contrast with these studies, a recent study on patients with type 1 diabetes mellitus[33] found no statistically significant association between SFA and CVD and all-cause mortality, nor between all-cause mortality risk and replacing 5 percent of energy from SFAs with energy from PUFAs, MUFAs or carbohydrates (Schoenaker *et al.,* 2012). However, the authors say the discrepancy with earlier studies that show a reduced CVD risk with replacement of SFAs by PUFAs may be explained by a lack of power in their study.

4.8.2 Studies that support reducing animal products and the argument for low-fat versus high-fat dairy products

This section considers some of the studies that are often cited in support of the reduction of animal fat/protein consumption, including dairy.

One of the best known ecological studies of diet and CHD is the Seven Countries Study, in which baseline surveys were carried out between 1958 and 1964 and a number of individual characteristics measured in 12 763 middle-aged men belonging to 16 cohorts in Finland, Greece, Italy, Japan, The Netherlands, the United States and former Yugoslavia (Menotti, Kromhout and Blackburn, 1999). A 25-year follow-up study reported a direct correlation between dietary fat and total cholesterol levels and between total cholesterol levels and coronary-related mortality. Significant positive correlations between CHD mortality were reported for

[32] A modified fat diet was considered to be one that aimed to include 30 percent or more energy from total fats, and included higher levels of monounsaturated or polyunsaturated fats than a "usual" diet. A low-fat diet was considered to be one that aimed to reduce fat intake to less than 30 percent of energy from fat, and at least partially replace the energy lost with carbohydrates (simple or complex), protein or fruit and vegetables.

[33] Patients with type 1 diabetes mellitus are at a markedly increased risk of CVD, and dietary recommendations for prevention and treatment of both CVD and diabetes have focused on reducing SFA intake and increasing fibre intake (Schoenaker *et al.*, 2012).

consumption of butter, meat, pastries, milk and sugar. In contrast, significant negative correlation coefficients were seen for legumes, alcohol and oils. Food patterns associated with high CHD mortality rates were characterized by high consumption of butter, dairy products and other animal products (excluding fish), usually rich in SFAs and cholesterol. The authors noted that their results justify interest in the Mediterranean diet for prevention of CHD, as it is rich in plant foods and relatively poor in animal foods.

Another large-scale study that supports cutting down high-fat dairy products is the North Karelia Project in Finland. This comprehensive community-based programme was started in 1972. The population of the neighbouring province Koupio was used as a control. At the start of the project, smoking among men was extremely common, and blood pressure levels and serum cholesterol levels were extremely high in North Karelia, ascribed to a diet high in saturated fat, especially dairy fat (Puska, 2010). Although the evaluation of the first five years of the project did not show any differences in the trends in coronary mortality between North Karelia and Kuopio (Salonen *et al.,* 1983), annual CVD mortality rates among the working age population in Finland as a whole have been reduced by 80 percent since 1969 (Puska, 2009). Total fat consumption has reduced from close to 40 percent of dietary energy to a little over 30 percent, with major reductions in saturated fat intake and some increase in polyunsaturated fat intake. The national butter consumption per capita has reduced from about 18 kg in 1965 to less than 3 kg in 2005 (Puska, 2009). Use of vegetable oil for cooking has increased from close to 0 percent in 1970 to about 50 percent. Fruit and vegetable consumption has increased and salt intake has reduced. The dietary changes have caused a remarkable reduction in blood cholesterol levels, with a subsequent reduction in blood pressure levels in men aged 30–59 years. However, there has been much criticism of both the original hypothesis and subsequent representation of results of the North Karelia Project (see Maijala, 2000 and references therein). The criticisms have included the claim that the decrease in CHD mortality rates seen in the population of the neighbouring province used as a control was similar to or even sometimes larger than those seen in North Karelia.

The DASH study was a multicentre, randomized controlled clinical trial involving 459 participants that tested the effects of dietary patterns on blood pressure (Appel *et al.,* 1997). For three weeks prior to the intervention phase, all subjects were fed a control diet that was low in fruits, vegetables and dairy products, with a fat content typical of the average diet in the United States.The intervention consisted of eight weeks on a "combination diet" that was rich in fruit and vegetables and low-fat dairy products. This was compared with subjects assigned to a control diet ("typical American diet") and with subjects assigned to a fruit-and-vegetable diet that provided high levels of potassium, magnesium, fibre, fruit and vegetables, and fewer snacks and sweets than the control diet. The combination diet reduced blood pressure more than the other two diets both in subjects with hypertension and in those without hypertension. The reductions in blood pressure were achieved after two weeks and sustained for six more weeks. The study concluded that a diet rich in fruits, vegetables and low-fat dairy foods and with reduced saturated and total fat contents can substantially lower blood pressure. The authors emphasized that DASH was an 11-week feeding study. As such, it was not designed to assess either

adherence to the diets among people selecting their own food or the long-term effects of the diets on blood pressure and clinical cardiovascular events. Although European guidelines on CVD prevention recommend healthy nutrition based on the DASH trial, whether this effect on CVD is due to low-fat dairy product intake is not yet proven (Soedamah-Muthu *et al.,* 2011). According to other authors, the DASH study was an efficacy-feeding study, not an effectiveness study; therefore, it may not have any effect on CHD events despite its known metabolic effects (Yancy *et al*., 2003).

The current recommendations by health authorities and governments to eat low-fat dairy foods in preference to high-fat dairy foods are also supported by the data published in 1999 from the Nurses Health Study (Hu *et al.,* 1999), which examined high- versus low-fat dairy foods. This was a large prospective cohort study of female nurses aged 34–59 years residing in the United States (baseline population greater than 80 000), and included a 14-year follow-up. This found that total fat intake was not significantly related to the risk of coronary disease. The study also showed that the ratio of high-fat dairy (whole milk, hard or cream cheese, ice cream and butter) to low-fat dairy (skim or low-fat milk, yoghurt and cottage cheese) consumed was positively associated with risk of CHD, even though separate analyses of intakes of high-fat and low-fat dairy food showed no significant association with CHD. Among the dairy products, consumption of whole milk was associated with a significantly increased risk of CHD. In contrast, a greater consumption of skim milk was associated with a non-significantly lower risk of CHD. Dairy foods were among the top five contributors to total saturated fat intake, with hard cheese contributing 11 percent of the intake and low-fat milk 4 percent.

Bernstein *et al.* (2010) found that higher intakes of red meat, red meat excluding processed meat, and high-fat dairy (whole milk, ice cream, hard cheese, full-fat cheese, cream, sour cream, cream cheese and butter) were significantly associated with elevated risk of CHD. Higher intakes of poultry, fish and especially nuts were significantly associated with lower risk. The authors concluded that the risk of CHD may be reduced by changing the sources of protein in the diet.

In the Cornell China Study, dietary, lifestyle and disease mortality data were collected in 1983 from 6 500 adults in 65 counties in rural China. People in rural China consumed one third less fat daily than people in the United States, 10 times less animal protein and three times more fibre and had profoundly less CVD (5.6- and 16.7-fold lower, for men and women, respectively) (Campbell and Chen, 1999). Energy intake per kg of body weight was about 30 percent higher in China than in the United States, but the prevalence of obesity was much lower in China. Higher animal protein intake in the United States was linked to higher blood cholesterol levels. Combined CHD mortality rates for men and women in rural China were found to be inversely associated with the intake of green vegetables. However, lifestyle factors other than diet (e.g. spirituality, levels of stress) (Mullin, 2010) and factors such as smoking, physical activity, adiposity etc. may have confounded these results.

The Mediterranean-style diet (MD), which refers to a dietary profile commonly available in the 1960s in the various countries bordering the Mediterranean Sea, has long been reported to have cardioprotective properties (Sofi *et al.,* 2010; Kastorini *et al.,* 2011). It is characterized by high consumption of MUFAs, primarily from

olives and olive oil, and encourages daily consumption of fruits, vegetables, whole grain cereals and low-fat dairy products;[34] weekly consumption of fish, poultry, tree nuts and legumes; a relatively low consumption of red meat, approximately twice a month; and a moderate daily consumption of alcohol, normally with meals (Kastorini *et al.,* 2011). A systematic review and meta-analysis of 18 prospective cohort studies covering over 2 million people with follow-up ranging from four to 20 years (Sofi *et al.,* 2010) found that a two-point increase of the score that estimates adherence to the MD was associated with a significant reduction of overall mortality (RR: 0.92; 95 percent CI: 0.90–0.94) and cardiovascular incidence or mortality (RR: 0.90; 95 percent CI: 0.87–0.93).[35] A recent meta-analysis that looked at six RCTs (total of 2 650 individuals) that compared an MD with low-fat diets in overweight/obese individuals with a minimum follow-up of 6 months, reporting intention-to-treat data on CVD risk factors found that the MD appears to be more effective than low-fat diets in inducing clinically relevant long-term changes in cardiovascular risk factors[36] and inflammatory markers (Nordmann *et al.,* 2011). Finally, a meta-analysis of 50 studies (a mix of clinical trials, prospective studies and cross-sectional studies) which included over 500 000 individuals and looked at the effect of the MD on MetS and its components found that adherence to the MD was associated with reduced risk of MetS and components of MetS[37] (Kastorini *et al.*, 2011).

4.8.3 Recent review studies on milk/dairy consumption with respect to cardiovascular disease

Although no adequately powered RCTs are available that isolated milk/dairy as the intervention, large cohort studies with prospectively collected baseline data on health, lifestyle and diet provide important information that can be used to assess the effect of milk and other dairy products on CHD risk. Several recent review studies have looked specifically at milk/dairy food consumption and CVD, some of which have conducted a meta-analysis of available cohort data. The key findings of review studies published during the last five years are summarized in Table 4.4.

Alvarez-León, Román-Viñas and Serra-Majem (2006) reported an inverse association between intake of dairy products and hypertension and stroke. The authors comment that low-fat dairy products fulfil the recommendation for a diet low in sodium and with adequate intakes of calcium, magnesium and potassium to prevent hypertension. Gibson *et al.* (2009) noted that, while dairy foods are a source of SFAs, there is no consistent evidence that consumption of dairy foods is

[34] The Mediterranean dietary pattern is not homogeneous. Although most authors seem to agree that it includes a moderate fat content (mainly from olive oil and nuts) and is rich in fruit, vegetables, legumes and complex carbohydrates, low in red meat and includes moderate consumption of fish and low to moderate amounts of red wine with meals, the role of dairy appears to be less clear cut.

[35] The study also found a significant reduction in cancer incidence or mortality (RR: 0.94; 95% CI: 0.92, 0.96) and neurodegenerative diseases (RR: 0.87; 95% CI: 0.81, 0.94).

[36] The individual risk factors were: weighted mean difference of body weight; BMI; systolic blood pressure; fasting plasma glucose; total cholesterol; and high-sensitivity C-reactive protein.

[37] The components studied were waist circumference; HDL cholesterol; triglycerides; systolic blood pressure; diastolic blood pressure; and glucose.

TABLE 4.4
Summary of recent review studies related to dairy consumption and risk of CVD

Reference	Dietary item	Type of review	Total CVD	CHD	Stroke	Hypertension	Ischaemic heart disease
Alvarez-León, Román-Viñas and Serra-Majem (2006)	Dairy products: "raw and processed or manufactured milk and milk-derived products" that included butter, cheese, ice cream, margarine, milk and cultured milk products (yoghurt)	Narrative review of 6 meta-analyses or systematic reviews on CHD			Reduced	Reduced	Possibly reduced
German *et al.* (2009)	"Dairy" not defined, but appears to include milk, butter, cheese	Narrative review. Data from 12 cohorts involving >280 000 subjects	7/12 cohorts found no association 3 cohorts reported positive relationships 1 cohort reported a positive relationship between CVD and butter, but a negative relationship with cheese				
German *et al.* (2009)	Cheese	Narrative review. Data from 12 cohorts involving >280 000 subjects	1 cohort reported a negative relationship Limited evidence indicates cheese most likely to be associated with reduced CVD risk				
Gibson *et al.* (2009)	Two cohorts used dairy foods as a group; 2 used milk intake; 3 measured calcium in dairy; 6 reported various combinations of dairy: butter, milk and cheese; milk and cheese; milk and butter; butter and cheese; or whole milk, skim milk, high- and low-fat dairy	Narrative review. Data from 12 cohorts involving >280 000 subjects	4 found no association 8 mixed findings No consistent evidence that dairy food consumption is associated with a higher risk of CHD				

TABLE 4.4 *(continued)*

Reference	Dietary item	Type of review	Total CVD	CHD	Stroke	Hypertension	Ischaemic heart disease
Elwood *et al.* (2008)	Milk (milk, whole milk, low-fat milk, high-fat milk); dairy products; dairy calcium	Meta-analysis of 15 studies (11 for heart disease, 7 for stroke)			Reduced (RR = 0.79; 95% CI: 0.75–0.82)		Reduced (RR = 0.83; 95% CI: 0.74–0.91) for milk; (RR = 0.84; 95% CI: 0.76–0.93) for milk/dairy
Elwood *et al.* (2010)	Milk	Systematic review. Meta-analysis of 38 cohort studies. Five case-control retrospective studies also described but not included in meta-analysis. Eleven cohorts for milk.			Reduced (RR = 0.79; 95% CI: 0.68–0.91)		Reduced (RR = 0.92; 95% CI: 0.80–0.99)
Elwood *et al.* (2010)	Butter	Systematic review. Butter: 5 cohort studies (3 included for meta-analysis) and several case-control studies	3 cohort studies suggest a possible reduction in vascular disease risk (RR = 0.93; 95% CI: 0.84–1.02), while 2 cross-sectional studies suggest an increase and 1 an increase in peripheral arterial disease				
Elwood *et al.* (2010)	Cheese	Systematic review. Cheese: 6 cohort studies (2 included for meta-analysis)	Using a fixed effects model, and weighting the studies appropriately: overall estimate of risk for vascular disease decreased (RR = 0.90; 95% CI: 0.79–1.03)				
Ralston *et al.* (2011)	Low-fat dairy	Systematic review and meta-analysis of 5 cohorts				Reduced (RR = 0.84; 95% CI: 0.74–0.95)	

TABLE 4.4 *(continued)*

Reference	Dietary item	Type of review	Total CVD	CHD	Stroke	Hypertension	Ischaemic heart disease
Ralston *et al.* (2011)	Fluid dairy foods	Systematic review and meta-analysis of 5 cohorts				Reduced (RR = 0.92; 95% CI: 0.87–0.98)	
Ralston *et al.* (2011)	Cheese	Systematic review and meta-analysis				No association	
Soedamah-Muthu *et al.* (2011)	Milk	Meta-analysis. Six prospective cohort studies	Reduced (modest inverse association) in 4 studies (RR = 0.94; 95% CI: 0.89–0.99).	No association in 6 studies. (RR = 1.0; 95% CI: 0.96–1.04)	Inverse association, but not statistically significant in 6 studies (RR = 0.87; 95% CI: 0.72–1.05)		
Soedamah-Muthu *et al.* (2011)	Total dairy	Meta-analysis. Four prospective cohorts	No significant association (RR = 1.02; 95% CI: 0.93–1.11).				
Soedamah-Muthu *et al.* (2011)	Total high-fat dairy	Meta-analysis. Four prospective cohorts	No significant association (RR = 1.04; 95% CI: 0.89–1.21).				
Soedamah-Muthu *et al.* (2011)	Total low-fat dairy products	Meta-analysis. Three prospective cohorts	No significant association (RR = 0.93; 95% CI: 0.74–1.17)				
Tholstrup (2006)	Dairy products	Narrative review		No strong evidence that dairy products increase risk of CHD			
Tholstrup (2006)	Regular hard cheese	Narrative review		Probable beneficial effect			
Tholstrup (2006)	Fermented milk	Narrative review				May be beneficial	

RR – relative risk; CI – confidence interval.

associated with higher risk of CHD. Elwood *et al*. (2008) conclude that the available data indicate a possible beneficial effect of milk and dairy consumption on risk of CVD. A recently published meta-analysis by the same group (Elwood *et al*., 2010) reported a 13 percent (95 percent CI: 2 percent–23 percent) reduction in risk of all-cause mortality in individuals with the highest dairy intake relative to those with the lowest intake and 8 percent (95 percent CI: 1 percent–20 percent) and 21 percent (95 percent CI: 9 percent–32 percent) reductions in risk of ischaemic heart disease (IHD) and stroke. From data from a total of 259 162 participants and 4 391 CHD cases (fatal and nonfatal) analysed in six prospective cohort, Soedamah-Muthu *et al.* (2011) concluded that milk intake was not associated with risk of CHD, stroke or total mortality. Using a subset of the data (13 518 participants and 2 283 CVD cases in four prospective cohort studies) the authors found that milk was modestly inversely associated with total CVD risk (RR: 0.94 per 200 ml/day; 95 percent CI: 0.89–0.99), although they caution that these findings are based on limited numbers. Furthermore, limited studies of the association of total high-fat and total low-fat dairy products showed no significant association with CHD risk (Soedamah-Muthu *et al.,* 2011). A narrative review concluded that when guiding dietary principles such as balance, variety and moderation are stressed, there is no strong evidence that dairy products increase the risk of CHD in healthy men of all ages or in healthy young and middle-aged women (Tholstrup, 2006).

Several new studies have been published since these reviews. A small 16-year prospective study of 1 529 adult Australians suggests that full-fat dairy may contribute to a reduction of CVD risk (Bonthuis *et al*., 2010). However, analysis of data from the Nurses Health Study (a large prospective cohort study of more than 100 000 participants) found that high-fat dairy products were significantly associated with elevated risk of CHD (Bernstein *et al*., 2010). Goldbohm *et al.* (2011) found that dairy fat intake (per 10 g/day; rate ratio (mortality) = 1.04; 95 percent CI: 1.01–1.06) is associated with slightly increased all-cause and IHD mortality rates in women, while a small prospective cohort study of 1 956 Dutch participants found that high-fat dairy was associated with an increased risk of CVD mortality (van Aerde *et al.,* 2012). The authors also report that when high-fat dairy was split into "desserts" and "non-desserts", a statistically significant association with increased risk of CVD was seen only with the "non-desserts" (hazard ratio [HR] per standard deviation [SD] increase = 1.28; 95 percent CI: 1.06–1.55), suggesting that fat rather than sugar was responsible. Total dairy intake and low-fat dairy were not found to be statistically significantly associated with CVD mortality or all-cause mortality (van Aerde *et al.,* 2012). Another recent prospective cohort (33 625 participants, 13-year follow-up) also found that total dairy was intake was not significantly associated with risk of CHD (HR per SD increase = 0.99; 95 percent CI: 0.94–1.05) or stroke (HR per SD increase = 95; 95 percent CI: 0.85–1.05), nor were high-fat dairy and low-fat dairy (Dalmeijer *et al.,* 2012).

Two recent large prospective cohort studies have reported results with regard to dairy consumption and stroke. Larsson, Virtamo and Wolk (2012) found that consumption of low-fat dairy foods was inversely associated with risk of total stroke and cerebral infarction. The relative risks reported for the highest quintile of low-fat dairy consumption (four servings/day) compared with the lowest quintile (zero servings/day) were 0.88 (95 percent CI: 0.80–0.97) for total stroke and 0.87

(95 percent CI: 0.78–0.98) for cerebral infarction. Consumption of total dairy, full-fat dairy and milk were not associated with stroke risk. In the second study, which looked at dietary protein sources and the risk of stroke, Bernstein *et al.* (2012) found that compared with one serving of red meat/day, one serving of low-fat dairy/day was associated with an 11 percent lower risk of stroke (95 percent CI: 5 percent–17 percent), and one serving of whole-fat dairy/day with a 10 percent lower risk (95 percent CI: 4 percent–16 percent).

4.8.4 Other dairy products and risk of cardiovascular disease

There is a paucity of studies examining individual dairy food items and CVD risk (Elwood *et al.,* 2010). Butter has a higher concentration of milk fat than any other dairy product, and is cholesterolemic (Tholstrup, 2006). However, controlled studies have demonstrated that milk and butter have similar cholesterolemic effects; the effects on other CHD risk markers have not been fully elucidated (Tholstrup, 2006). An inconsistency between results from cohort studies and case-controlled studies with respect to butter has been highlighted by Elwood *et al.* (2010): a meta-analysis of data from three cohorts suggested a possible reduction in vascular disease risk (0.93; 95 percent CI: 0.84–1.02), although this was not statistically significant (*P = 0.33*), while two case-control studies suggested an increase of vascular disease, and one case-control study an increase in peripheral arterial disease from the consumption of butter. A more recent study (Goldbohm *et al.,* 2011) reported a slightly increased risk of all-cause and IHD mortality for both butter and dairy fat intake (per 10 g/day; rate $\text{ratio}_{\text{mortality}}$ = 1.04; 95 percent CI: 1.01–1.06) only in women. As Elwood *et al.* (2010) concluded, the main message of these data is that the evidence on butter and the other dairy items is inadequate.

Ghee, an important source of fat in the Indian diet derived from cow and buffalo milk, is rich in SFAs and cholesterol (Nath and Ramamurthy, 1988; Rawashdeh, 2002; Mohammadifard *et al.,* 2010). High consumption of vegetable ghee,[38] clarified butter (Indian ghee) and milk, in conjunction with a sedentary lifestyle and higher BMI have been reported to be significant risk factors for CVD in Indians (Singh *et al.*, 1996). However, Indian men consuming 1 kg or more of ghee per month have been found to have a significantly lower prevalence of CHD than those who consumed less than 1 kg/month (Gupta and Prakash, 1997). Shankar *et al.* (2002, 2005) found that consumption of ghee at the level of 10 percent of dietary energy in a vegetarian diet had no effect on serum lipid profiles or lipoprotein profiles in healthy young subjects.

Evidence on cheese and vascular disease is also limited (Elwood *et al.,* 2010). Although six cohort studies evaluating cheese and CVD risk were available, sufficient data for a meta-analysis were given in only two, yielding an overall estimate of risk from cheese of 0.90 (95 percent CI: 0.79–1.03) (Elwood *et al.,* 2010). Tholstrup

[38] Vegetable ghee is solidified vegetable oil, made to mimic anhydrous butter oil, i.e. ghee.

(2006) concluded from reviewing three well-controlled human studies[39] that cheese does not increase plasma cholesterol. However, one older study (Appleby *et al.*, 1999, cited in Tholstrup, 2006) found that both meat and cheese consumption were positively associated with total cholesterol concentration and dietary fibre intake was inversely associated with total cholesterol concentration in both men and women. Tholstrup (2006) recommends that a possible beneficial effect of cheese on CHD risk factors be further investigated. The author also notes that CHD mortality is low in France, where cheese consumption is high, whereas CHD mortality was high in the Scandinavian studies, where milk consumption is high, but that ecological studies such as these are not easy to interpret, and the author could not establish causality. A recent large prospective cohort study found no association between consumption of cheese and stroke risk (Larsson, Virtamo and Wolk, 2012).

With regard to fermented milk, Tholstrup (2006) wrote that some specific bacterial strains may have cholesterol-reducing properties, while some fermented products (especially those produced using *Lactobacillus helveticus*) can decrease hypertension. In addition, a recent study reported a statistically significant inverse relationship between fermented milk consumption and CVD, with the highest level of intake (238 g/day for women, 273 g/day for men) being associated with 15 percent decreased incidence of CVD compared with the lowest level of intake (40 g/day for women and 43 g/day for men) (Sonestedt *et al.,* 2011). Goldbohm *et al.* (2011) also reported that consumption of fermented full-fat milk was inversely associated with all-cause mortality for men ($RR_{continuous}$ = 0.91; 95 percent CI: 0.86–0.97 per 100 ml/day) and for women ($RR_{continuous}$ = 0.92; 95 percent CI: 0.85–1.00 per 100 ml/day), and nonsignificantly with stroke mortality in both men and women. Recently, Dalmeijer *et al.* (2012) reported a borderline inverse association between intake of fermented dairy products and risk of stroke (HR = 0.92; 95 percent CI: 0.83–1.01), supporting this result. However, another smaller study (van Aerde *et al.*, 2012) did not find fermented dairy products to be statistically significantly associated with CVD mortality or all-cause mortality.

Elwood *et al.* (2010) records the few available studies dealing with cream, yoghurt and ice cream, but draws no firm conclusions. They note that a very small number of the cohort studies provide evidence on individual dairy foods, and that there is no convincing evidence of harm or benefit from consumption of the separate food items.

4.8.5 Summary

Interpreting the interactions between consumption of dairy products and CVD is difficult, not least because of the limitations of the studies reviewed outlined in the

[39] The first study (Tholstrup *et al.*, 2004, cited in Tholstrup *et al.*, 2006) compared the effects of isoenergetic amounts of milk, cheese and butter (adjusted to the same content of lactose and casein) on fasting and postprandial blood lipids and lipoproteins, and on postprandial glucose and insulin response. All food items other than milk, cheese and butter were constant and identical in the three test diets. The cheese diet contained 205 g of hard cheese, "Samsø". The second study (Biong *et al.*, 2004, cited in Tholstrup, 2006) compared the effects of Jarlsberg cheese with butter on serum lipoproteins, haemostatic variables and homocysteine. The third study (Nestel *et al.*, 2005, cited in Tholstrup, 2006) compared the effects of a daily consumption of 40 g of dairy fat as butter or as matured cheddar cheese.

introduction to this chapter. In addition, substitution of one type of fat for another or reducing total fat intake invariably results in a range of food substitutions such that intake of other macro- and micronutrients is altered (Skeaff and Miller, 2009). Furthermore, many efforts to modify dietary intake of fat have included efforts to change one or more other elements of dietary and non-dietary behaviour, e.g. increasing fibre intake, fruit and vegetable consumption or physical activity, or reducing meat consumption, body weight, smoking, salt intake or alcohol consumption. The multifactorial nature of the dietary interventions and accompanying changes in dietary patterns makes it difficult to disentangle the specific effects of one nutrient/food from other components of the diet (Skeaff and Miller, 2009). Another limitation may be that in most within-population studies, those who drink milk are compared with those who do not but who are still consuming a Western-type diet, not a healthier diet such as the Mediterranean diet.

Early studies have associated high-fat, high-protein ASF, including milk and dairy, with increased risk of CVD. However, some of these studies included dairy only as a component of the diet, and often included other dietary interventions and lifestyle changes. It is clear that saturated fat intake increases blood cholesterol levels and the occurrence of CVD. The recent expert consultation on fats and fatty acids (FAO and WHO, 2010) recommended that SFAs should be replaced with PUFAs to decrease the risk of CHD. The panel did not find convincing evidence for significant effects of total dietary fat on CHD (FAO and WHO 2010), but concluded that industrial trans fatty acids increase CHD risk factors and events, and recommended a total TFA intake of less than 1 percent of energy in the diet. Replacing SFAs with largely refined carbohydrates has no benefit on CHD, and may even increase the risk of CHD.

Although dairy foods contribute to SFA content of the diet, other components in milk such as calcium and PUFAs may reduce risk factors for CHD. The majority of meta-analyses of available prospective studies show that low-fat milk and total dairy product consumption is generally not associated with CVD risk, and may actually contribute to a reduction of CVD. A recent small prospective study suggests that this may hold true for full-fat dairy too (Bonthuis *et al*., 2010), although other studies have found no association between total dairy, low-fat dairy or high-fat dairy and CHD or stroke (Dalmeijer *et al.,* 2012) or that high-fat dairy products were significantly associated with elevated risk of CHD (Bernstein *et al*., 2010) and increased risk of CVD mortality (van Aerde *et al.*, 2012). Furthermore, in women, dairy fat intake has been associated with slightly increased all-cause and IHD mortality rates (Goldbohm *et al.*, 2011). With regard to dairy consumption and stroke, two recent large prospective cohort studies have found that intake of low-fat dairy foods was inversely associated with risk of stroke and cerebral infarction, and that replacing a serving of red meat in the diet with a serving of low-fat or high-fat dairy was associated with a lower risk of stroke.

Much of the available data concern milk; information on other dairy products and CVD is scarce, although preliminary data suggest that fermented milk may have a beneficial role in hypertension, a risk factor for CVD. In observational studies, specific dietary patterns have been identified that are associated with decreased risk of CVD. These include the DASH-style diet and the Mediterranean diet. Both these diets include milk/dairy in moderate amounts, with low-fat dairy specified in the DASH-diet.

4.9 DAIRY INTAKE AND CANCER

Genetics and environmental factors both contribute to the development of cancer (ACS, 2005). Heredity accounts for approximately 5–10 percent of all cancers (ACS, 2005) while it is estimated that about 30 percent of cancer deaths are related to poor nutrition and lifestyle (WHO, 2011b). Although a high intake of dietary fat has been implicated in the development of some cancers, including colon, breast, and prostate cancers, FAO and WHO (2010) concluded that there is no probable or convincing evidence for significant effects of total dietary fat on cancer. Similarly, the panel concluded that there is insufficient evidence for establishing any relationship between consumption of SFAs and cancer (FAO and WHO, 2010). Of primary concern was the possible relationship between total dietary fats and overweight and obesity (FAO and WHO, 2010). However, WCRF and AICR (2007) states that there is convincing evidence that obesity, weight gain and overweight short of obesity increase the risk of cancers of the colorectum, oesophagus (adenocarcinoma), endometrium, pancreas and kidney, and of postmenopausal breast cancer.

Dairy foods and calcium consumption have been hypothesized to play different roles depending on individual cancer sites (as discussed in the following sections). Some components in milk and dairy products such as calcium, vitamin D, sphingolipids, butyric acid and milk proteins may be protective against cancer (Parodi, 1998; Parodi, 1999; Parodi, 2001; Parodi, 2003; Parodi, 2004; Garland *et al*., 2006; German and Dillard, 2006; Holt *et al*., 2006). Both the positive and negative associations of milk and dairy products with various types of cancer and possible mechanisms are discussed in the sections below. As the literature on milk/dairy consumption and cancer is extensive, this review is limited to the findings of recent WCRF reports (see Section 4.9.6).

4.9.1 Colorectal cancer

Colorectal (including anal) cancer is the third most common cancer in the world. An estimated 1.24 million people worldwide were diagnosed with colorectal cancer in 2008, with almost 60 percent of cases being in the developed world. There is wide geographical variation in incidence, much of which can be attributed to differences in diet, particularly the consumption of red and processed meat, fibre and alcohol, and to differences in body weight and physical activity. Incidence rates of colorectal cancer are increasing in countries where rates were previously low as diets become more westernized.

Several studies, including animal, in vitro, epidemiological and human clinical studies, have investigated a possible protective role for dairy foods, and particularly dairy food nutrients, such as calcium and vitamin D, in colon cancer. Calcium in milk may play a protective role in colon cancer, given that intracellular calcium directly influences cell growth and apoptosis, and bioactive constituents in milk may also play a role in the protective effects of milk on colorectal cancer (WCRF and AICR, 2007).

4.9.2 Breast cancer

Breast cancer is the leading cause of death from cancer in females worldwide, estimated to be responsible for almost 460 000 deaths in 2008. An estimated 1.38 million women across the world were diagnosed with breast cancer in 2008, accounting for 23 percent of all cancers diagnosed in women. Determinants of breast cancer include

age; body fatness; reproductive factors and lactation, as well as age at menarche and menopause; childbearing; exogenous and endogenous hormone concentrations and metabolism; history of benign breast disease; exposure to radiation; alcohol consumption; and family history of breast cancer (Key, Verkasalo and Banks, 2001; Brekelmans, 2003; WCRF and AICR, 2008a).

The major hypotheses for why consumption of dairy products may increase risk of breast cancer include the following: 1) high dietary total and saturated fat intake;[40] 2) milk products may contain pesticides that may be carcinogenic; and 3) milk may contain growth factors, including IGF-1, which may promote breast cancer cell growth (Moorman and Terry, 2004). However, some components in dairy products, such as calcium, vitamin D, rumenic acid, butyric acid, branched chain fatty acids and whey protein may protect against breast cancer (Moorman and Terry, 2004; Parodi, 2005).

4.9.3 Prostate cancer

Prostate cancer is the most commonly diagnosed cancer in men living in Western countries and the second most common cause of cancer-related death in men (ACS, 2005; Parodi, 2009). The major established risk factors are age, family history and country/ethnicity (Cancer Research UK, 2012).

Various mechanisms have been hypothesized by which milk and/or dairy product consumption may influence prostate cancer development. These include the following: 1) calcium suppresses the production of calcitriol (1,25-dihydroxyvitamin D), thus increasing cell proliferation in the prostate; 2) consumption of milk (the calcium in milk in particular) increases blood levels of IGF-1, which may cause cell proliferation; 3) fat and SFA[41]; 4) metabolites of branched-chain fatty acids may be carcinogenic; and 5) presence of oestrogens which may be carcinogenic. These, and the possible role of fat and SFAs, have been examined in detail by Parodi (2009).

4.9.4 Bladder cancer

Worldwide an estimated 150 000 people died from bladder cancer in 2008. Exogenous factors such as dietary and lifestyle characteristics may contribute to the

[40] A number of the mechanisms have been proposed for how dietary fat influences development of breast cancer (WCRF and AICR, 2007). For example, higher endogenous oestrogen levels after menopause are a known cause of breast cancer, and dietary fat is relatively well established as a cause of increased endogenous oestrogen production. An alternative mechanism by which dietary fat could influence steroid hormone levels is that increased serum-free fatty acids could displace oestradiol from serum albumin, thus increasing free oestradiol concentration. However, the serum concentration of sex-hormone-binding globulin is a more important determinant of the proportion of oestradiol that can enter the breast epithelial cells. Sex-hormone-binding globulin decreases with increasing body mass index and insulin resistance. Energy-dense diets (among other factors) lower the age of menarche. Early menarche is an established risk factor for breast cancer. However, FAO and WHO (2010) concluded that there is no probable or convincing evidence for significant effects of total dietary fat on cancer; and insufficient evidence for establishing any relationship between consumption of SFAs and cancer.

[41] The authors do not provide a possible mechanism. Please note that the FAO/WHO (2010) Expert Consultation on Fats and Fatty Acids concluded that there is no probable or convincing evidence for significant effects of total dietary fat on cancer; and insufficient evidence for establishing any relationship between consumption of SFA and cancer.

increased risk of malignancy (Huxley *et al.*, 2009), with cigarette smoking believed to cause almost 50 percent of cases in high-income countries (WCRF and AICR, 2007). As most metabolites are excreted through the urinary bladder, food such as milk could influence the risk of bladder cancer (Larsson *et al.*, 2008).

4.9.5 Childhood consumption of milk and dairy products and risk of cancer in adulthood

Recent research has focused on the "programming effects" of milk via the IGF-1 axis, as discussed in Section 4.3.5 (van der Pols *et al.*, 2007; Martin, Holly and Gunnell, 2011). High concentrations of IGF-1 are associated with an increased risk of prostate, breast and colorectal cancer (Hoppe, Mølgaard and Michaelsen, 2006). The Boyd Orr study found that a family diet rich in dairy products during childhood resulted in a greater risk (with a near-tripling of the odds) of colorectal cancer in adulthood (van der Pols *et al.*, 2007). Milk intake was also associated with colorectal cancer risk. However, high milk intake was weakly inversely associated with prostate cancer risk. Childhood dairy intake was not associated with breast and stomach cancer risk, while a positive association with lung cancer was confounded by smoking during adulthood (van der Pols *et al.*, 2007). Some of these finding are in contrast to findings of adult intake by WCRF and AICR (2007) (see below).

4.9.6 Recommendations by the World Cancer Research Fund/American Institute for Cancer Research

WCRF and AICR (2007) examined the relationship between diet and the risk of cancer. The key aims of the report were to summarize, assess and judge the most comprehensive body of evidence yet collected and displayed on the subject of food, nutrition, physical activity, body composition and the risk of cancer. To keep the evidence current and updated into the future, an ongoing review of scientific literature is carried out under the Continuous Update Project (CUP). The CUP provides an impartial analysis and interpretation of the data as a basis for reviewing and, where necessary, revising WCRF/AICR's Recommendations based on the Second Expert Report. Table 4.5 shows the relationship between milk and dairy product consumption and cancer, as identified by the report (WCRF and AICR, 2007, 2008a, 2008b).

WCRF and AICR (2007) concluded that milk probably protects against colorectal cancer and that there is limited evidence suggesting that milk also protects against bladder cancer. There is limited evidence that cheese is a cause of colorectal cancer. Diets high in calcium are a probable cause of prostate cancer and there is limited evidence suggesting that high consumption of milk and dairy products is a cause of prostate cancer. These conclusions were supported by WCRF and AICR (2008a, 2008b). However, WCRF and AICR (2008a, 2008b) were not able to reach a conclusion regarding the relationship between milk and dairy products and breast cancer due to insufficient data. Although the reports emphasized that the overall recommendation is not for diets containing no meat or foods of animal origin, they note that most diets that are protective against cancer are mainly made up from foods of plant origin.

Several review studies on the role of milk and dairy and risk of cancer have been published recently (Lampe, 2011; Li *et al.*, 2011; Mao *et al.*, 2011; Aune *et al.*, 2012).

TABLE 4.5
Relationship between milk and dairy product consumption and cancer

Cancer	Predictor	Number of studies	Pooled relative risk and heterogeneity	Comments
Colorectal	Milk	4 cohorts	0.94 (95% CI 0.85–1.03) per serving/day, with low heterogeneity	Milk probably protects against colorectal cancer There is limited evidence suggesting that cheese is a cause of colorectal cancer Epidemiological evidence for cheese intake is consistently in contrast to the probable protective effect from milk No specific mechanism has been identified but cheese could plausibly cause colorectal cancer through the indirect mechanisms connected to saturated fats
	Milk	10 cohorts	0.78 (95% CI: 0.69–0.88) for the highest intake group when compared to the lowest	
	Cheese	3 cohorts	1.14 (95% CI: 0.82–1.58) per serving/day, with low heterogeneity	
	Cheese	2 cohorts	1.11 (95% CI: 0.88–1.39) per 50 g/day, low heterogeneity	
	Calcium	10 cohorts	0.98 (95% CI: 0.95–1.00) per 200 mg/day, with low heterogeneity	
	Calcium	8 cohorts	0.95 (95% CI: 0.92–0.98) per 200 mg/day, with no heterogeneity	
Breast	Milk & dairy			Limited evidence, no conclusions
Prostate	Milk	8 cohorts	1.05 (95% CI: 0.98–1.14) per serving/day, with low heterogeneity	There is limited evidence suggesting that milk and dairy products are a cause of prostate cancer Diets high in calcium are a probable cause of prostate cancer Milk could plausibly cause prostate cancer through the actions of calcium. Also, consumption of milk increases blood levels of IGF-1, which has been associated with increased prostate cancer risk in some studies
	Milk	6 case-control	1.08 (95% CI: 0.98–1.19) per serving/day, with moderate Heterogeneity	
	Milk & dairy products	8 cohorts	1.06 (95% CI: 1.01–1.11) per serving/day, with moderate heterogeneity	
	Milk & dairy products	5 case-control	1.03 (95% CI: 0.99–1.07) per serving/day, with low heterogeneity	
	Calcium	8 cohorts	1.27 (95% CI: 1.09–1.48) per g/day, with moderate heterogeneity	
	Calcium	3 case-control	1.16 (95% CI: 0.64–2.14) per gram of calcium/day, with high heterogeneity	
Bladder	Milk	4 cohorts	0.82 (95% CI 0.67–0.99) per serving/day, with moderate heterogeneity	There is limited evidence suggesting that milk protects against bladder cancer
	Milk	3 case-control	1.00 (95% CI: 0.87–1.14) per serving/day, with high heterogeneity	

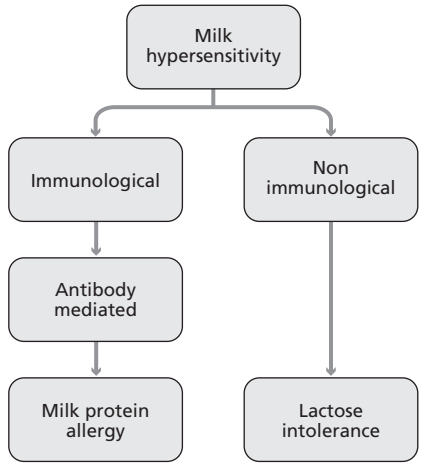
CI – confidence interval.
Sources: WCRF and AICR (2007, 2008a, 2008b).

The conclusions of Lampe (2011), that "meta-analyses of cohort data available to date support an inverse association between milk intake and risk of colorectal and bladder cancer and a positive association between diets high in calcium and risk of prostate cancer", and of Aune *et al*. (2012), "that milk and total dairy products, but not cheese or other [individual] dairy products, are associated with a reduction in colorectal cancer risk", were consistent with those of WCRF and AICR (2007, 2008a, 2008b). With regard to bladder cancer, while Mao *et al*. (2011) concluded that milk may be related to the reduction of bladder cancer risk, Li *et al*. (2011) reported that their findings were not supportive of an independent relationship between the intake of milk or dairy products and the risk of bladder cancer. Both Mao *et al*. (2011) and Li *et al*. (2011) observed differences between geographical areas, which may reflect the different compositions of dairy products consumed in different parts of the world or ethnic differences; this warrants further research. Other areas where further research is needed include the effect of specific dairy products and constituents of dairy products such as rumen-derived metabolites and live microbes present in some dairy products on cancer risk.

4.10 MILK HYPERSENSITIVITY

Hypersensitivity to milk may be attributed to either lactose or protein in milk (Figure 4.2). Sensitivity to cow-milk protein causes varying degrees of injury to the intestinal mucosal surface (Heyman, 2006). In contrast, ingestion of dairy products resulting in symptoms of lactose intolerance generally leads to transient symptoms without causing harm to the gastrointestinal tract (Heyman, 2006).

FIGURE 4.2
Milk hypersensitivity: difference between milk allergy and intolerance



Source: Adapted from Johansson *et al*., 2001 and Monaci *et al*., 2006.

4.10.1 Lactose intolerance and malabsorption

Lactose is the principal carbohydrate in milk. Cow, goat and buffalo milk contain less lactose than human milk. Lactose is a disaccharide composed of the two simple sugars, glucose and galactose. An enzyme, lactase (a β-galactosidase), is required to hydrolyse lactose into the simpler sugars in order for humans to digest and then absorb the sugars. In adults with lactase deficiency (also called lactase non-persistance, LNP), lactose is not digested in the upper bowel and reaches the lower bowel, where it is fermented by gut micro-organisms, which produces hydrogen, carbon dioxide and methane gas. Undigested lactose also draws water into the intestinal lumen through its osmotic effect, which increases motility and can cause diarrhoea. Symptoms include abdominal pain, bloating and flatulence. Thus, low lactase levels cause lactose malabsorption (or lactose maldigestion). When lactose malabsorption gives rise to symptoms, this is called "lactose intolerance", i.e. lactose malabsorption is the physiologic problem that manifests as lactose intolerance. The definitions used by the American Academy of Pediatrics Committee on Nutrition (Heyman, 2006) are given in Box 4.1. Lactose maldigestion does not lead to symptoms of lactose intolerance in all LNP subjects, and a small percentage of LNP subjects remain free of symptoms even after ingestion of large amounts of lactose (Scrimshaw and Murray, 1988). Although rarely life-threatening, the symptoms of lactose intolerance can lead to significant discomfort and disrupted quality of life (Heyman, 2006).

Lactase deficiency in adults is a normal developmental phenomenon characterized by the down-regulation of lactase activity, which occurs soon after weaning in most ethnic groups (EFSA, 2010). Lactose maldigestion increases with age during adulthood (Goulding *et al.*, 1999). The lactase persistence trait is more common in populations that practice cattle herding and dairying (Swallow, 2003), and is related to genetic selection of individuals with the ability to digest lactose (Heyman, 2006). Children of some ethnic groups commonly lose lactase at one to two years of age (e.g. Thai children) while in others lactase persists until later in life (10–20 years of age) (e.g. Finnish children) (Sahi, 1994; Wang *et al.*, 1998). According to some estimates, approximately 70 percent of the world's population has primary lactase deficiency (Heyman, 2006). The frequency of lactose maldigestion varies widely among populations but is high in nearly all but those of Northern European origin (Table 4.6) (Scrimshaw and Murray, 1988; Heyman, 2006). Lactase deficiency in Europe has been reported to vary between 4 percent (in Denmark and Ireland) and 56 percent (in Italy) (Ingram *et al.,* 2009a, cited in EFSA, 2010). In South America, Africa and Asia, over 50 percent of the population are reported to have lactase nonpersistence, and in some Asian countries this rate is almost 100 percent (Lomer, Parkes and Sanderson, 2008). However, because definitions vary from study to study and subjects are not generally representative of the whole population, the exact incidence is unknown. The symptoms attributed to lactose intolerance are also common in the absence of lactose ingestion as they can sometimes be attributed to other components of the diet, and are highly susceptible to a placebo effect (Shaukat *et al.,* 2010, cited in EFSA, 2010).

In individuals who are diagnosed with lactose intolerance, avoidance of foods that contain lactose, such as milk, will relieve symptoms. However, most individuals can tolerate some dairy products and can progressively increase tolerance because

BOX 4.1
Definitions of types of lactose intolerance

- Lactose intolerance is a clinical syndrome of one or more of the following: abdominal pain, diarrhoea, nausea, flatulence, and/or bloating after the ingestion of lactose or lactose-containing food substances. The amount of lactose that will cause symptoms varies from individual to individual, depending on the amount of lactose consumed, the degree of lactase deficiency and the form of food substance in which the lactose is ingested.
- Lactose malabsorption is the physiologic condition that manifests as lactose intolerance and is attributable to an imbalance between the amount of ingested lactose and the capacity for lactase to hydrolyse the disaccharide.
- Primary lactase deficiency is attributable to relative or absolute absence of lactase that develops in childhood at various ages in different racial groups and is the most common cause of lactose malabsorption and lactose intolerance. Primary lactase deficiency is also referred to as adult-type hypolactasia, lactase nonpersistence or hereditary lactase deficiency.
- Secondary lactase deficiency is lactase deficiency that results from small bowel injury, such as acute gastro-enteritis, persistent diarrhoea, small bowel overgrowth, cancer chemotherapy or other causes of injury to the mucosa of the small intestine and can present at any age but is more common in infancy.
- Congenital lactase deficiency is extremely rare. Affected newborn infants present with intractable diarrhoea as soon as human milk or lactose-containing formula is introduced. Unless this is recognized and treated quickly, the condition is life-threatening because of dehydration and electrolyte losses. Teleologically, infants with congenital lactase deficiency would not have been expected to survive before the twentieth century, when no readily accessible and nutritionally adequate lactose-free human-milk substitute was available.
- Developmental lactase deficiency is now defined as the relative lactase deficiency observed among preterm infants of less than 34 weeks' gestation.

Source: Heyman, 2006.

TABLE 4.6
Prevalence of acquired primary lactase deficiency

Examples of groups among whom lactase deficiency predominates (60%–100% lactase deficient)	Examples of groups among whom lactase persistence predominates (2%–30% lactase deficient)
Near East and Mediterranean: Arabs, Ashkenazi Jews, Greek Cypriots, southern Italians	Northern Europeans
Asia: Thais, Indonesians, Chinese, Koreans	Africa: Hima, Tussi, nomadic Fulani
Africa: south Nigerians, Hausa, Bantu	India: individuals from Punjab and New Delhi
North and South America: black Americans, Latinas, Eskimos, native Canadians and Americans, Chami-speaking native Colombians	

Source: Adapted from Heyman, 2006.

colonic bacteria can adapt to utilize the hydrogen gas produced in fermentation (Hertzler and Savaiano, 1996). It has been suggested that unhydrolysed lactose behaves as a prebiotic (defined as a non-digestible food ingredient that has a beneficial effect through its selective metabolism in the intestinal tract), which causes the adaptation of the colonic microflora (Lomer, Parkes and Sanderson, 2008).

Fermented milk products such as yoghurt (plain yoghurt more so than flavoured) have been shown to be tolerated by lactose-intolerant individuals (Heyman, 2006; Lomer, Parkes and Sanderson, 2008). The bacteria in the yoghurt partially digest the lactose into glucose and galactose (and the glucose to lactic acid); in addition, yoghurt's semisolid state slows gastric emptying and gastrointestinal transit, resulting in fewer symptoms of lactose intolerance (see Heyman, 2006). Aged cheeses tend to have lower lactose content than other cheeses and, thus, may also be better tolerated. Predigested milk or dairy products with lactase are available in some countries and will often permit a lactose-intolerant individual to be able to take some or all milk products freely (Heyman, 2006).

The EFSA Panel on Dietetic Products, Nutrition, and Allergies concluded that it is not possible to determine a single threshold of lactose for all lactose-intolerant subjects because of the great variation in individual tolerance. Although symptoms of lactose intolerance have been described after intake of less than 6 g of lactose in some subjects, the Panel concluded that the vast majority of subjects with lactose maldigestion will tolerate up to 12 g of lactose as a single dose (particularly if taken with food) with minor or no symptoms. Higher daily doses of up to 24 g may be tolerated if distributed throughout the day (EFSA, 2010). The EFSA panel also stated that the available evidence was insufficient to draw any conclusions with respect to calcium absorption in dairy products in which lactose has been hydrolysed (i.e. where technological processes have been applied to remove lactose from products), but that no negative nutritional consequences can be expected if they only differed from conventional dairy products in lactose content (EFSA, 2010).

4.10.2 Milk-protein allergies

Cow-milk allergy (CMA) is one of the most common food allergies in childhood (Monaci *et al.,* 2006). Incidence of allergy to cow-milk protein falls between 2 percent and 6 percent worldwide (Hill and Hosking, 1997; Hosking, Heine and Hill, 2000; Fiocchi *et al*., 2010). The perception of milk allergy is reported to be far more frequent than confirmed CMA (Fiocchi *et al*., 2010). Allergy to cow-milk protein primarily occurs in infancy and childhood and is often outgrown by age five, although 15–20 percent of allergic children become permanently allergic with increased levels of immunoglobulin E (IgE) and, more especially, cow-milk-specific IgE (Monaci *et al.,* 2006). CMA is often the first food allergy to develop in a young infant and often precedes the development of allergies to other foods such as eggs and peanuts (Fiocchi *et al*., 2010).

CMA is an IgE-mediated reaction to cow milk and may induce cutaneous (atopic dermatitis, urticaria, angioedema), respiratory (rhinitis, asthma, cough) and gastrointestinal (vomiting, diarrhoea, colic, gastro-oesophageal reflux) reactions, and in some extreme cases even systemic anaphylaxis. Although an allergic reaction can develop to any of the many milk proteins, β-lactoglobulin, a whey protein not present in human breast milk, and casein have been implicated most often in cow-milk

allergies. Casein content of cow milk is approximately double that of human milk. In addition, the predominant type of casein differs between cow milk and human milk: human milk has a higher content of β-casein, which is more sensitive to peptic hydrolysis than α_S-casein, particularly α_{S1}-casein, which predominates in cow milk.

Milk allergens are known to preserve their biologic activity even after boiling, pasteurization, ultra-high-temperature processing and evaporation for the production of powdered infant formula (Fiocchi *et al.,* 2010). Prevention of CMA largely relies on avoidance of all food products containing cow-milk proteins. Milk from some other species may also need to be avoided: milk allergens of various mammalian species cross-react, with high sequence homology among cow-, sheep- and goat-milk proteins (Fiocchi *et al.,* 2010). The recent guidelines issued by the World Allergy Organization state that goat, sheep, and buffalo milk should not be used as a substitute for children with cow-milk allergy as they can expose patients to severe reactions (Fiocchi *et al*., 2010). Camel milk can be considered a valid substitute for children more than two years old. Mare and donkey milks can be considered as valid cow-milk substitutes, in particular (but not exclusively) for children with delayed-onset CMA.

4.11 CURRENT NATIONAL RECOMMENDATIONS FOR MILK AND DAIRY CONSUMPTION

Milk and dairy product recommendations for 42 countries are shown in Table 4.7. As national food-based dietary guidelines are designed to reflect factors such as local food availability, cost, nutritional status, consumption patterns and food habits, recommendations vary widely. Twenty-six countries recommend the consumption of low-fat or non-fat milk. Specified fat content varies from 0.1–1.5 percent fat in the Bulgarian guidelines to 1.5–2.5 percent in New Zealand, with most stringent specifications in Denmark (maximum 0.7 percent fat). Some countries, such as Argentina, Australia, New Zealand, Philippines and the United Kingdom exclude children from low-fat recommendations, although the age up to which high-fat dairy is recommended for children varies: 2 years in Australia and the United Kingdom, 5 years in New Zealand and 12 years in Philippines. According to WHO (2004), semi-skimmed milk may be acceptable for feeding non-breastfed children more than 12 months old. However, skimmed milk is not recommended as a major food source during the first two years of life because it does not contain essential fatty acids, lacks fat-soluble vitamins and has a high potential renal solute load in relation to energy. A few countries (Bulgaria, France, Norway and Turkey) mention choosing salt-reduced dairy products when possible, while avoiding sugar-added products is mentioned in the guidelines from Cuba, Ireland, Malaysia, Norway and the United States.

Some countries, including Chile, France, Norway, Oman and the United Kingdom, either specifically mention that cow milk should not be given to infants below one year of age or that recommendations apply to children of more than one year of age, while other countries recommend exclusive breastfeeding up to six months of age (Cuba, Dominican Republic, El Salvador, France, India and Nepal). Some give specific recommendations for various vulnerable groups such as pregnant and breastfeeding women or the elderly.

Most countries recommend at least one serving of milk daily, with some countries recommending up to three servings per day. Notable exceptions include El Salvador

(at least three times a week) and Guatemala (at least twice a week). Although serving sizes vary, most recommendations are for about 500 ml of milk per day. Exceptions (excluding those for pregnant/lactating women) are Canada (adolescents 14–18 years old are recommended to consume three to four servings (750–1 000 ml)/day; Spain (adult women: three to four portions of milk of portion size 200–250 ml); Ireland (adolescents: at least five servings [945 ml; serving size 1/3 of a pint]) and South Africa (children 7–13 years: 500–750 ml milk) per day. Countries that recommend very small daily amounts are: Oman (0.3 cup for children of one to five years old and 0.5 cup for all other age groups apart from males 14–18 years [1 cup]); the Netherlands (children one to three years old: 300 ml); Cuba (children of 7–17 years old and adults of 18–60 years old: one cup of milk); Philippines (240 ml for most groups); and China (300 g as a general recommendation). Many countries include other dairy foods such as cheese, yoghurt, custard, ice cream, evaporated milk, powdered milk and fermented milk in their recommendations, although portion sizes for these are not always specified. The United States excludes cream, sour cream and cream cheese from its recommendations because of the low calcium content in these foods. France excludes ice cream and milk-based desserts with added sugar, and the United Kingdom excludes butter and cream.

4.12 CONCLUSION

In this chapter we examine scientific evidence related to the health benefits and risks of milk and dairy consumption. It is not feasible to complete a comprehensive health outcome assessment, however, the main points are discussed within the chapter and a summary of the findings are presented in Table 4.8.

Much has been written on the impact of milk consumption on health, yet more research is needed, particularly on individual dairy food items. Milk and dairy provide key nutrients essential for growth and development and milk consumption is associated with a reduced risk of NCDs such as osteoporosis and possibly colorectal cancer and T2DM. However, concern has been, and continues to be, expressed about the association between high dairy consumption and other NCDs, such as CVD and prostate cancer. Gaps exist in the research literature and randomized control intervention studies, although expensive, may be needed to examine the long-term impact of dairy on health. Based on current information, milk and dairy products can represent an important part of a healthy diet, as long as consumption levels are not excessive; however any diet that exceeds the daily energy requirements over a sustained period can lead to potentially significant health risks.

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ANNEX

TABLE 4.7
Milk and dairy product recommendations from 42 countries

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
OCEANIA	***Australia***					
	Children and adolescents	4–7 years	2 servings	1 serving is: Milk: 250 ml or 1 cup Evaporated milk: 40 g or 0.5 cup Cheese: 2 slices Custard: 250 ml or 1 cup Yoghurt: 200 g or 1 small carton	*Dietary guidelines for Australians*, 2003. Australian Government, Health and Ageing Department and National Health and Medical Research Council	Reduced-fat milks are not suitable for young children under 2 years of age because of their high energy needs, but low- or reduced-fat varieties (1 or 2% fat) should be encouraged for older children and adolescents instead of full-cream milk (4% fat). The term milks, yoghurts and cheeses, as used in this guideline, generally refers to cow milk and the yoghurt and cheese produced from it but can also include milks, yoghurts and cheeses from goat and sheep milks.
		8–11 years	2 servings			
		12–18 years	3 servings			
	Adults	19–60 years	2 servings			
		60+ years	2 servings			
	Pregnant and breastfeeding women		2 servings			
	New Zealand					
	Children	2–12 years	500 ml or 2–3 servings	1 serving is: Milk: 250 ml Yoghurt: 150 g or 1 unit Cheese: 40 g or 2 slices Ice cream: 140 g or 2 scoops	Food and nutrition guidelines for different age groups, 2008–2010. Ministry of Health	Choose reduced-fat milk (1.5–2.5% fat). Non-fat milk is not recommended for children under 5 years of age.
	Adolescents		3 servings			
	Adults		At least 2 servings			Choose reduced- or low-fat options.
	Pregnant and breastfeeding women		At least 3 servings			

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
NORTH AMERICA	***USA***					
	2–3 years		2 cups	1 cup is: Milk or yoghurt, fat-free or low-fat: 1 cup milk Fortified soy beverage, or yoghurt: 1 cup 1.5 oz. natural cheese (e.g. cheddar) 2 oz. of processed cheese (e.g. American)	*Dietary guidelines for Americans*, 2010. US Department of Agriculture and US Department of Health and Human Services	Choose fat-free or low-fat (1%) milk and dairy products (including lactose-free and lactose-reduced products and fortified soy beverages, yoghurts, frozen yoghurts, dairy desserts and cheeses). Cream, sour cream and cream cheese are not included in these recommendations due to their low calcium content.
	4–8 years		2.5 cups			
	9–18 years		3 cups			
	Canada					
	Children	2–3 years	2 food guide servings	1 food guide serving is: Milk or powdered milk (reconstituted): 250 ml or 1 cup Canned milk (evaporated): 125 ml or 0.5 cup Yoghurt: 175 g or 0.75 cup Kephir: 175 g or 0.75 cup Cheese: 50 g or 0.5 oz.	*Eating well with Canada's food guide*, 2007. Health Canada	Choose skimmed (1 or 2% fat) milk or lower-fat milk alternatives.
		4–8 years	2 food guide servings			
		9–13 years	3–4 food guide servings			
	Adolescents	14–18 years	3–4 food guide servings			
	Adults	19–50 years	2 food guide servings			
		51+ years	3 food guide servings			

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***Austria***				
	General recommendation	3 portions/ servings of milk and dairy products	1 portion/serving is: Milk: 200 ml Yoghurt: 180–250 g Curd: 200 g Cottage cheese: 200 g Cheese: 50–60 g	*The Austrian food pyramid*, 2010. Austrian Federal Ministry of Health	Choose low-fat milk and dairy products.
	Belgium				
	6+ years	Milk, dairy (450 ml or 3–4 small glasses) and cheese (1–2 slices or 20–40 g)	1 glass milk (150 ml) is: Buttermilk: 150 ml or 1 glass Yoghurt: 150 ml or 1 glass 1 serving of milk with breakfast cereal or muesli Ayran: 150 ml or 1 glass Cheese, 20% fat: 1 slice Cheese, 15% fat or light cheese: 1 slice Cheese as a snack: 2 cubes Cottage cheese as a snack: a jar or a cup Pudding, custard and porridge: 1 cup Milkshake: 150 ml	*Dietary and exercise guidelines for Belgians*, 2009. Flemish Institute for Health Promotion	Choose low-fat and skimmed milk and cheese with a fat content less than 30%.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE					
Bulgaria					
	General recommendation	Milk and dairy products (yoghurt, cheese, curds, cream and milk-based products, etc.): yoghurt or milk (200 ml or 1 glass) and cheese (50 g)		*Food-based dietary guidelines for adults in Bulgaria*, 2006. Ministry of Health, National Centre of Public Health Protection	Chose milk and dairy products with low or reduced fat (0.1–1.5% fat) and salt content. Consume yoghurt more frequently.
Denmark					
	General recommendation	500 ml of milk		*The diet compass: the road to a healthy balance. 8 dietary guidelines*, 2009. Danish Ministry of Food, Agriculture and Fisheries	Choose skimmed-milk, buttermilk or yoghurt with maximum 0.7% of fat. Recommendations are made on the basis of the Nordic Nutrition Recommendations 2004 prepared by a Nordic expert group.
Finland					
	General recommendation	500 ml of milk, sour/butter milk or liquid yoghurt		*National Nutrition Council*, 2005. Ministry of Agriculture and Forestry	Choose fat-free or low-fat (1% fat) milk and dairy products. Choose low-fat cheese options.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***France***				
	0–6 months	Exclusive breastfeeding during the first 6 months		*Nutrition guides for different population groups*, 2002–2007. French agency for food, environmental and occupational health & safety (anses [former afssa]), and Ministry of Labour, Employment and Health	
	6–12 months	Milk (≥ 500 ml [from the mother or an infant formulae]); they can also can be given yoghurt and cheese			
	1–3 years	Milk (≤ 800 ml)			
	3–11 years	3–4 dairy products (depending on the size and calcium content). Dairy products include: cow milk or milk from other animals and their dairy products; yoghurts, fermented milk, soft or hard cheese			Choose semi-skimmed milk. Ice creams and desserts with a milk base that have added sugar are not included in these recommendations.
	Adolescents	3–4 dairy products (depending on the size and calcium content)			Choose high-calcium, low-fat and low-salt yoghurt and cheese. Choose a variety of products.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***France*** *(continued)*				
	55+ years	3–4 dairy products			Choose high-calcium, low-fat and low-salt yoghurt and cheese, such as milk, yoghurt, fresh cheese etc. Choose a variety of products.
	Pregnant women	3–4 dairy products	1 dairy product is: Milk: 150 ml or 1 glass Yoghurt: 125 g or 1 unit Cheese, Emmental-type: 20 g		Choose high-calcium, low-fat and low-salt cheeses. Eat only cheese spread and pressed cheeses (such as Emmental, Gruyere, Parmesan) and remove the crust.
	General recommendation (3+ years)	3 milk or dairy products			Choose high-calcium, low-fat and low-salt cheeses. Limit fatty and sugary dairy-desserts.
	Germany				
	General recommendation	Consume milk and dairy products daily		*10 guidelines of the German Nutrition Society (DGE) for a wholesome diet German Nutrition Society*	
	Greece				
	General recommendation	2 servings of milk, cheese or traditional yoghurt		*Dietary guidelines for adults in Greece*, 1999. Supreme Scientific Health Council, Ministry of Health and Welfare	

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE					
Hungary					
	General recommendation	3–4 units of milk and dairy products	1 unit is: Milk, milk drink, yoghurt, kephir, fermented (curdled) milk: 200 ml or 1 glass Low-fat cottage cheese: 50 g Cheese: 30 g Processed cheese: 2 pieces (cubes/ wedges)	*Dietary guidelines to the adult population in Hungary*, 2001. Special Board of Internal Medicine, Ministry of Health of Hungary	Choose low-fat dairy products (1.5 grams or less/100 grams) with as little added sugar as possible. Recommendations are made on the basis of the Nordic Nutrition Recommendations 2004 prepared by a Nordic expert group.
Iceland					
	General recommendation	2 servings of milk or dairy products a day (e.g. 2 glasses of milk)		*Dietary guidelines for Iceland*, 2005. Public Health Institute of Iceland	
Ireland					
	General recommendation	3 servings	1 serving is: Milk: ⅓ of a pint Yoghurt: 1 carton Cheddar cheese, Edam or Blarney: 1 oz.	*The food pyramid*, 2005. Irish Nutrition and Dietetic Institute	Choose low-fat choices frequently. Low-fat milk is not suitable for young children.
	Adolescents	At least 5 servings			
	Pregnant and breastfeeding women	At least 5 servings			

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***Italy***				
	General recommendation	Milk: 125 g or 1 cup Yoghurt: 125 g or a small portion Fresh cheese: 100 g or a medium portion Aged cheese: 50 g or a medium portion		*Italian guidelines for healthy eating*, 2003. National Institute for Research on Food and Nutrition, Ministry of Agricultural, Food and Forestry Policies	Choose low-fat or skimmed milk.
	The Netherlands				
	1–3 years	Milk and dairy products: 300 ml Cheese: 10 g or 0.5 slice		*Food choice guidelines*, 2011. The Netherlands Nutrition Centre	
	4–8 years	Milk and dairy products: 400 ml Cheese: 10 g or 0.5 slice			
	9–13 years	Milk and dairy products: 600 ml Cheese: 20 g or 1 slice			

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***The Netherlands*** *(continued)*				
	14–18 years	Milk and dairy products: 600 ml Cheese: 20 g or 1 slice			
	19–50 years	Milk and dairy products: 450 ml Cheese: 30 g or 1.5 slice			
	51–70 years	Milk and dairy products: 500–550 ml Cheese: 30 g or 1.5 slice			
	70+ years	Milk and dairy products: 650 ml Cheese: 20 g or 1 slice			
	Norway				
	General recommendation	500 ml of milk		*Norwegian dietary guidelines*, 2005. Norwegian Directorate of Health	Choose dairy products with low fat, low salt and little sugar added. Recommendations are made on the basis of the Nordic Nutrition Recommendations 2004 prepared by a Nordic expert group.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***Poland***				
	General recommendation	At least 2 large glasses of low-fat milk		*Poland's FBDG status, communication and evaluation*, 2009. National Food and Nutrition Institute	Milk could be substituted for yoghurt and kephir and partly for cheeses.
	Portugal				
	General recommendation	2–3 portions	1 portion is: Milk: 250 ml or 1 cup Liquid yoghurt: 200 g or 1 unit Solid yoghurt: 200 g or 1.5 units Aged cheese: 40 g or 2 slices Fresh cheese: 50 g or 0.25 unit) Cottage cheese: 100 g or 0.5 unit	*A new food guide for the Portuguese population*, 2003. Faculty of Nutrition and Food Sciences, University of Porto; Consumer Institute, Council of Ministers' Presidency; and Saude XXI, Operational Health Programme	
	Spain				
	Children	500–1 000 ml milk and dairy products (cheese, yoghurt, milk-based desserts, etc.)		*Guide for healthy eating*, 2004. Spanish Society for Community Nutrition (SENC) and Ministry of Health	

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***Spain*** *(continued)*					
	General recommendation		2–4 portions	1 portion is: Milk: 200–250 ml or 1 cup Yoghurt: 200–250 g or 2–3 units/small cartons Aged cheese: 40–60 g or 2–3 slices Fresh cheese: 85–125 g or 1 individual portion		Prefer low-fat milk and dairy products.
	Elderly		3 portions			
	Women	Adult	3–4 portions			
		Pregnant	2–3 portions			
		Breast feeding	3 portions			
	Sweden					
	Healthy adults		500 ml of milk or 300–400 ml of milk or yoghurt and two slices of cheese	100 ml of milk are equivalent to 10–15 g of cheese	*Swedish National Food Administration*, 2005	Choose low-fat cheese (17% fat or less) and dairy products. Cheese consumption should not be greater than 20 g/day. Recommendations are made on the basis of the Nordic Nutrition Recommendations 2004 prepared by a Nordic expert group.
	Breastfeeding women		500 ml of skimmed milk, natural skimmed sour milk or natural low-fat yoghurt			
	Pregnant women		500 ml of skimmed milk, natural skimmed sour milk or natural low-fat yoghurt			Avoid cheese made from unpasteurized milk. Also avoid mould-ripened or washed-rind cheese even if it is made of pasteurized milk, for example brie, gorgonzola, chèvre, vacherol and taleggio. Cheese used in cooking that has been heated until it is bubbling is quite safe to eat.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE					
Switzerland					
	General recommendation	3 portions	1 portion is: Milk: 200 ml Yoghurt: 150–180 g Fresh/cottage cheese: 200 g Cheese: 30–60 g	*Recommendations for healthy, tasty eating and drinking for adults*, 2005. Swiss Society for Nutrition	
	Elderly	3–4 portions			
Turkey					
	Adults	2 servings or at least 500 g	1 serving is: Milk and yoghurt: 200 ml Cheese: 2 matchboxes size	*Dietary guidelines for Turkey*, 2004. The General Directorate of Primary Health Care of the Ministry of Health of Turkey, Department of Nutrition and Dietetics of the Hacettepe University	Choose non-fat or low-fat milk and dairy products. Choose yoghurt (ayran) and cheese with low salt.
	Children, adolescents, pregnant women and women after menopause	3–4 servings			

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
EUROPE	***United Kingdom***				
	General recommendation	Eat some milk and dairy foods every day: milk, cheese, yoghurt, fromage frais, cottage cheese, cream cheese, quark		*The eat well plate*, 2011. Department of Health in association with the Welsh Assembly Government, the Scottish Government and the Food Standards Agency in Northern Ireland	Choose lower-fat options when you can or have just a small amount of the high-fat varieties less often. Butter and cream are not included in this group.
	Pregnant women				Pregnant women should drink only pasteurized milk. They should not drink unpasteurized goat or sheep milk, or eat foods that are made with them, such as soft goat cheese. They should avoid soft blue cheeses and soft cheeses such as brie and camembert and others with a similar rind, whether pasteurized or unpasteurized.
	Infants				Cow milk should not be given as a drink until a baby is a year old. Children should drink full-fat milk until they are at least 2 years old. Like cow milk, goat and sheep milk are not suitable as drinks for babies under a year old, because they do not contain the right balance of nutrients. Providing they are pasteurized, ordinary full-fat goat and sheep milk can be used as drinks once a baby is a year old.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
LATIN AMERICA					
Argentina					
	Infants	Exclusive breastfeeding until 6th month			
	General recommendation for adults	2 cups (breakfast type) of milk	1 cup of milk is: Powdered milk: 2 heaped tablespoons Yoghurt: 1 unit Fresh cheese: 1 portion about the size of a matchbox Cheese spread, full fat: 6 heaped tablespoons Grated cheese: 3 tablespoons	*Dietary guidelines for the Argentinean population*, 2003. Ministry of Health	Choose low-fat dairy products for adults and full-fat for children and seniors.
	Children, adolescents, pregnant and lactating women	3 cups (breakfast type) of milk			
Chile					
	0–6 months	Exclusive breastfeeding		*Food guide for children less than 2 years*, 2005. Ministry of Health	Cow milk is not adequate for children younger than 1 year.
	12–23 months	400–500 ml If infant formula is used: based on cow milk (18–26% fat)			

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
LATIN AMERICA	***Chile*** *(continued)*					
	Children	2–5 years	3 cups	1 cup is: Milk: 1 cup Yoghurt: 1 unit Fresh cheese: 1 piece Aged cheese: 1 slice	*Food guide for a healthier life*, 2007. Institute of Nutrition and Food Technology (INTA), and the University of Chile	Choose low-fat milk and dairy products.
		10–18 years	3–4 cups			
	Adults	19–30 years	3 cups			
		30–59 years	3 cups			
		60+ years	2–3 cups			
	General recommendation		Milk and dairy products (no specific recommendations)			
	Cuba					
	Infants	0–2 years	Exclusive breastfeeding until 6 months of age. If needed, use cow or goat infant formula		*Food based dietary guidelines for Cuban children less than 2 years of age*, 2009. Institute of Nutrition and Food Hygiene, Ministry of Public Health	

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
LATIN AMERICA	***Cuba*** *(continued)*					
	Children	3–6 years	2 portions	1 portion is: Milk: 1 cup Yoghurt: 240 g Powdered milk: 24 g or 4 tablespoons Cheese: 30 g or 1 slice	*Food based dietary guidelines for Cubans older than 2 years of age*, 2009. Institute of Nutrition and Food Hygiene, Ministry of Public Health	Choose low-fat milk and dairy products. Add little sugar to milk and dairy products.
		7–13 years	1 portion			
		14–17 years	1 portion			
	Adults	18–60 years	1 portion			
		60+ years	1.5 portion			
		Pregnant and breast feeding women	3 portions			
	Dominican Republic					
	0–6 months		Exclusive breastfeeding		*Food and nutrient dietary guidelines for the Dominican Republic*, 2009. Pan American Health Organization (PAHO); Institute of Nutrition of Central America and Panama (INCAP); FAO; the State Secretary of Public Health and Social Assistance (SESPAS)	
	General recommendation					No specific recommendations are given.

TABLE 4.7 *(continued)*

Region and country	Age/population group	Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
LATIN AMERICA	***El Salvador***				
	General recommendation	Consume milk, dairy products (and eggs) at least three times a week		*Food and nutrition guide for Salvadorian families by population groups*, 2009. Ministry of Public Health and Social Assistance	Choose low-fat milk and dairy products.
	0–6 months	Exclusive breastfeeding			Breastfeeding can be continued up to 2 years of age, together with complementary feeding starting at 6 months of age.
	2–4 years	2 glasses of milk			Choose low-fat milk and dairy products.
	10–19 years	Milk and dairy products (cheese, cottage cheese and yoghurt) three times a week			
	Guatemala				
	General recommendation	Consume milk, dairy products (and eggs) at least twice a week		*Dietary guidelines for Guatemala: the seven steps for a healthy diet*, 1999. Institute of Nutrition of Central America and Panama (INCAP)	No specific recommendations are given.

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
LATIN AMERICA	***St. Kitts & Nevis***					
	General recommendation		Eat food from animals (which include milk) daily		*Food based dietary guidelines for St. Kitts & Nevis*, 2010. Health Promotion Unit, Ministry of Health; Pan American Health Organization (PAHO); FAO	No specific recommendations are given.
MIDDLE EST	***Oman***					
	Children and adolescents	1–5 years	0.3 cup	1 food serving: Milk: 1 cup Yoghurt: 1 cup Natural cheese, e.g. cheddar: 45 g Processed cheese: 60 g	*The Omani guide to healthy eating*, 2009. Department of Nutrition, Ministry of Health	Choose fat-free or low-fat varieties of milk and dairy products.
		6–14 years	0.5 cup			
		Males 14–18	1 cup			
		Females 14–18	0.5 cup			
	Adults and elderly	19–70 years	0.5 cup			
		70+	0.5 cup			
		Pregnant women	0.5 cup			
		Lactating women				

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
ASIA	***China***					
	General recommendation		300 g of milk and dairy products		*Chinese dietary guidelines*, 2007. Chinese Nutrition Society	Choose low fat and skimmed milk.
	Breastfeeding women		500 ml			
	Japan					
	General recommendation		2 servings of milk and dairy products		*The dietary guidelines for Japanese*, 2000. Ministry of Health, Labour and Welfare and Ministry of Agriculture, Forestry and Fisheries	
	India					
	Breastfed infants		200 ml of top milk		*Dietary guidelines for Indians*, 2011. National Institute of Nutrition	Exclusive breastfeeding should be practised at least for 6 months; breastfeeding can be continued up to 2 years.
	Infants	6–12 months	5 portions	1 portion is: Milk: 100 ml		
	Children	1–9 yrs	5 portions			
	Adolescents	10–18 yrs	5 portions			
	Adults		3 portions			
	Pregnant women and breastfeeding women (until 6th month)		5 portions			

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
ASIA	***Malaysia***					
	General recommendation		1–3 servings		*Malaysian dietary guidelines*, 2010. Ministry of Health	Milk sources are cows, goats and sheep. Choose milk and dairy products that are low in sugar. Individuals who need to reduce weight should choose low-fat dairy products.
	Nepal					
	Infants 6–12 months	Breastfed	Milk (200 ml)			Exclusive breastfeeding for children under 6 months and continue up to 2 years.
		Non-breastfed	Milk (500 ml)			
	Children	1–9 years	Milk (500 ml)			
	Adolescents	10–18 years	Milk (500 ml)			
	Adults		Milk, curd or butter milk (320 ml or 2 glasses)			

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
ASIA	***Philippines***					
	Growing children	1–12 years	Whole milk (240 ml or 1 glass) or its equivalents	1 glass whole milk is equivalent to: Powdered whole milk: 4 tablespoons Evaporated milk diluted in 1 glass of water: 0.5 cup	*Nutritional guidelines for filipinos*, 2000. National Nutrition Council	
	Adolescents		Whole milk (240 ml or 1 glass) or its equivalents			
	Adults	Pregnant/ lactating woman	Whole milk (240 ml or 1 glass) or its equivalents			
		Healthy adult	Whole milk (240 ml or 1 glass) or its equivalents			
	Thailand					
	General recommendation		Milk (1–2 glasses) or yoghurt (1–2 cups)	1 glass is: Milk: 200 ml	*Food based dietary guideline for Thai*, 2001. Developed by the Institute of Nutrition, Mahidol University and distributed by Nutrition Division, Department of Health, Ministry of Public Health	
	Viet Nam					
	General recommendation		Have milk and dairy products properly for each age.		*Vietnam food-based dietary guidelines*, 2006–2010. National Institute of Nutrition	

TABLE 4.7 *(continued)*

Region and country	Age/population group		Daily recommendations of milk and dairy products	Translation of recommendations, weight of portions/ servings and household measures	Reference/responsible entity	Comments
AFRICA	***South Africa***					
	Children	7–13 years	Milk (500–750 ml or 2–3 cups)		*South African guidelines for healthy eating for adults and children over the age of seven years*, 2004. Department of Health	Adults should choose low-fat or fat-free milk. Milk recommendations include maas, yoghurt, sour milk and cheese.
	Adolescents	14–25 years	Milk (250–500 ml or 1–2 cups)			
	Adults	25–60 years	Milk (250 ml or 1 cup)			
	Elderly people	60+ years	Milk (250 ml or 1 cup)			

TABLE 4.8
Health benefits and risks of consuming milk and dairy products

Benefits	Risks
As a source of macro- and micronutrients	
Milk and dairy are a source of energy and high-quality protein, and make a significant contribution to requirements for calcium, magnesium, selenium, riboflavin, vitamin B_{12} and pantothenic acid.	Cow milk does not contain appreciable amounts of iron and presents a high renal solute load to infants compared with breast milk, owing to its higher contents of minerals and protein. According to WHO guidelines, no undiluted cow milk should be given to infants younger than 12 months of age unless accompanied by iron supplements/iron fortified foods, although cheese and yoghurt may be given after 6 months.
Dietary dairy in growth and development	
Cow milk is associated with increased linear growth and can help prevent stunting, especially during the first 2 years of life. In children with poor nutritional status, milk is likely to supply nutrients that are important for growth and are deficient in the diet, while in well-nourished children the effect of milk on linear growth is likely through stimulation of IGF-1.	Greater adult stature is not always associated with better health. The factors that lead to greater adult attained height, or its consequences, increase the risk of cancers of the colorectum and breast (postmenopause), and probably increase the risk of cancers of the pancreas, breast (premenopause) and ovary. Height is also generally accepted to be a risk factor for osteoporotic fractures.
Dietary fat from milk is important in the diets of infants and young children and especially in populations with a very low fat intake. May help in the treatment of undernutrition (moderate malnutrition).	About 60% of milk fat consists of SFAs, including lauric acid (C12:0), myristic acid (C14:0) and palmitic acid (C16:0). Milk is a major contributor to ruminant trans fatty acid in the diet.
Dietary dairy and bone health	
Milk contains calcium and protein, important for bone health, and some dairy products also provide other nutrients that support bone health, such as potassium, zinc, vitamin A, and, if fortified, vitamin D.	Calcium requirements vary depending on dietary factors such as intake of vitamin D, animal source proteins and sodium and other factors such as physical activity and sun exposure. This may explain the "calcium paradox", i.e. that hip fracture rates are higher in developed countries where calcium intake is higher than in developing countries where calcium intake is lower.
The impact of dietary dairy products on bone health depends on life stage. Milk avoidance is possibly associated with increased risk of fracture in children. Milk consumption in childhood may protect against the risk of osteoporotic fractures in postmenopausal women. For older people in countries with high fracture risk, there is convincing evidence for a reduction in risk of osteoporotic fracture with sufficient intake of vitamin D and calcium together (especially in people who have very low intakes of calcium, vitamin D or both). Dairy can reduce the risk of calcium-deficiency rickets.	However, milk consumption during adult life does not appear to be associated with reduced risk of fracture.
Oral health	
Milk may have anticariogenic properties.	

TABLE 4.8 *(continued)*

Benefits	Risks
Weight gain and obesity development	
Observational evidence does not support the hypothesis that dairy fat contributes to obesity. There may be a protective effect of milk and dairy on weight due to components such as protein. However, if such an effect exists the magnitude is likely to be small.	Dairy is a dense energy source and energy balance is critical to maintaining healthy body weight. Cross-sectional epidemiological studies indicate that high dairy food intake can contribute to weight management, but prospective studies and randomized controlled intervention trials have yielded inconsistent results. Whether dairy consumption in childhood has an etiologic role in the development of obesity in later life is an open area of discussion.
Metabolic syndrome and type 2 diabetes	
There is moderate evidence showing an association between milk and dairy product consumption and lower incidence of T2DM in adults. Some studies suggest that dairy food consumption may have a beneficial impact on some MetS components.	There is limited evidence demonstrating that milk and dairy product consumption is associated with the reduced risk of MetS.
Cardiovascular disease	
Although dairy foods contribute to SFA content of the diet, other components in milk such as calcium and PUFAs may reduce risk factors for CHD. The majority of review studies conducting meta-analyses of prospective studies conclude that low-fat milk and total dairy product consumption is generally not associated with CVD risk, and may actually contribute to a reduction of CVD. Results for full-fat dairy and CVD risk are mixed.	Dairy products contain SFAs. SFAs may increase LDL cholesterol and risk of CVD. Industrial trans fatty acids are associated with an increased risk of CHD. The evidence regarding ruminant trans fats and CVD risk is inconclusive.
Cancer	
Some components in milk and dairy products such as calcium, vitamin D (fortified milk), sphingolipids, butyric acid and milk proteins may be protective against cancer. Milk and calcium probably protect against colorectal cancer. Limited evidence suggests that milk protects against bladder cancer.	Childhood milk consumption may have an effect on subsequent cancers in adulthood via the IGF-1 axis. Limited evidence suggesting that cheese is a cause of colorectal cancer. Diets high in calcium and high consumption of milk and dairy may be a cause of prostate cancer.
Milk hypersensitivity	
	Lactose is the principal carbohydrate in milk. Lactose malabsorption (or maldigestion) caused by low lactase levels manifests as lactose intolerance. According to some estimates, approximately 70% of the world's population has primary lactase deficiency. Incidence of CMA is reported to fall between 2% and 6% worldwide. Milk from other animal species such as goat, sheep, and buffalo should also be avoided by those with CMA.

CHD – coronary heart disease; CMA – cow-milk allergy; CVD – cardiovascular disease; IGF – insulin-like growth factor; LDL – low-density lipoprotein; PUFAs – polyunsaturated fatty acids; SFA – saturated fatty acid; T2DM – type 2 diabetes mellitus.

Chapter 5
Dairy components, products and human health

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ABSTRACT
This chapter opens with an overview of the main dairy components and their associated health effects. The following section explores the health impact of fermented and fortified foods in which nutrient contents have been increased or decreased. Traditional means, such as fermentation, can be employed to add nutritive value to the final product. The nutritional profile can be improved by adding nutrients that are not naturally present in milk, such as iron, plant sterols and stanols, a process known as fortification. Nutritional composition can be modified by reducing or removing dairy components such as fat and lactose. Innovation in the production of dairy products offers a valuable growth opportunity for the food and beverage industries in an era when consumers are more health conscious and aware of the connection between diet and health. Many countries are revising their regulatory frameworks to protect consumers from misleading advertising and labelling concerning health and nutrition claims, and the final section of this chapter reviews these changes and their implications for the dairy industry and the consumer.

Keywords: milk, nutrition, health, fat, protein, bioactive peptides, fermentation, fortification, health and nutrition claims

5.1 INTRODUCTION
Milk and fermented dairy products have a long history of use, as far back as the seventh millennium BC (Evershed *et al.,* 2008). In recent decades, technological innovations have led to a wide variety of dairy products, some of which have had components, such as fat and lactose, removed or contents reduced and others of which have been fortified with components, such as iron, sterols and vitamin D. Heightened awareness of the connection between diet and health has increased the demand for certain types of products, such as those with low fat and low calorie contents and products to which vitamins and minerals have been added (EUFIC, 1996).

When considering the health impact of dairy foods, it is critical to evaluate the impact of the food as a whole, and not just the individual nutrients. Dairy products

can vary greatly in their nutritional composition.[42] Industrial processes that alter the nutritional composition may not improve the overall nutritional profile. For example, low-fat foods typically compensate for the fat reduction by an increase in carbohydrates. As a result, dairy foods labelled as low fat may contain as many calories per serving as dairy foods without this label and may have higher sugar content (Wansink and Chandon, 2006). Skimmed milk (also known as "fat-free" or "non-fat" milk) contains less fat-soluble vitamins, particularly vitamin A, than whole milk. Hence, reduced-fat milk may be fortified with vitamins to replace the vitamins that were removed during the removal of milk fat.

In countries such as Chile, India and Mexico fortification of milk with iron and other micronutrients has improved iron status and reduced anaemia among younger, undernourished children[43] (Stekel *et al*., 1988; Villalpando *et al*., 2006; Sazawal *et al*., 2007). The mass fortification of milk with vitamin D contributed to the eradication of nutritional rickets in some developed countries (WHO and FAO, 2006). Milk products enriched with n-3 long-chain polyunsaturated fatty acids (LC-PUFAs) have the potential to contribute to improved nutrition (Givens and Gibbs, 2008; Lopez-Huertas, 2010).

Given the diversity of dairy products that are available on the market, and considering the wide variability in their nutritional compositions, it is important that accurate information is available to the consumer to help them make informed nutritional choices. Products such as whey and probiotic beverages are now advertised as offering health benefits beyond their regular nutritional value. To date, however, many dairy products lack the scientific evidence that substantiate such claims (Roupas, Williams and Margetts, 2009, and references therein).

The dairy industry is in a pivotal position to distribute health and nutrition information through advertising and labelling. When this information coincides with government public health recommendations, the industry can assist in promoting health (Fulponi, 2009). But when messages conflict, industry advertising can limit the efficacy of government messages. A Canadian study on butter, for example, concluded that despite increasing evidence of the potential danger of high blood cholesterol levels, industry advertising increased demand for butter (Chang and Kinnucan, 1991). Hence, the regulatory framework is currently being revised in many countries to ensure that consumers receive accurate information and are protected from misleading marketing campaigns, and also to encourage innovation in the dairy industry (Roupas, Williams and Margetts, 2009; Falguera, Aliguer and Falguera, 2012).

This chapter gives a very broad overview of the range of dairy components and products and their impact on human health. It is not a systematic review, therefore its findings and implications should be considered indicative.

[42] Chapter 3 provides detailed information on the nutritional composition of milks from various species and dairy products produced from them.

[43] Fortified milk programmes are discussed in Chapter 7.

5.2 DAIRY COMPONENTS

5.2.1 Milk fat and human health

Milk fat is highly complex, consisting of a large number of fatty acids and other lipid molecules that have various effects on human health. For example, cow milk[44] contains approximately 3.3 g of fat/100 g. This consists primarily of triacylglycerols (97–98 percent of total lipids by weight), which are composed of fatty acids of various lengths (4–24 carbon atoms) and levels of saturation. More than 400 fatty acids have been identified in milk fat. Whole milk contains approximately 1.9 g of saturated fatty acids (SFAs)/100 g. The monounsaturated fatty acid (MUFA) oleic acid (C18:1 *cis*-9) is the most abundant unsaturated fatty acid in milk (about 0.8 g/100 g of whole milk). Whole milk contains approximately 0.2 g of PUFA/100 g (Haug, Høstmark and Harstad, 2007). Up to five percent of the fatty acids in cow milk may be ruminant-derived *trans* fatty acids (TFAs), which are different from industrially-produced *trans* fats with respect to health outcomes (FAO and WHO, 2010a).

Concerns about obesity and cardiovascular disease (CVD) in developed and developing countries have increased public interest in minimizing the consumption of fats. Such concerns have prompted the dairy industry to develop technologies to modify milk fat content, which is evident from the range of liquid milk varieties that are available. While there may be a need for populations in high-income countries to reduce overall fat and calorie intake to avoid the risk of developing diet-related chronic diseases such as diabetes and CVD, many developing countries face the challenge of increasing fat consumption in populations with low-fat and overall low-energy intakes (FAO and WHO, 2010a).

Individual fatty acids

The relationship between milk fat intake and health impact is complex (German *et al.*, 2009) and much has been written on the association between dairy and CVD risk factors. As reported in the FAO and WHO expert consultation on fats and fatty acids (FAO and WHO, 2010a), it is recommended that total intake of SFAs should not exceed 10 percent of energy intake and SFAs should be replaced with PUFAs in the diet to reduce the risk of coronary heart disease (CHD). Individual SFAs have differing impacts on blood lipids. For example, lauric (C12:0), myristic (C14:0) and palmitic (C16:0) acids are associated with elevated serum levels of low-density lipoprotein (LDL)-cholesterol, whereas stearic acid (C18:0), which is poorly absorbed in the gut, has no effect on LDL-cholesterol (Shingfield *et al.*, 2008; FAO and WHO, 2010a; Gibson, 2011).

Cholesterol is an important component of cell membranes and is a precursor of bile acids, vitamin D and adrenal and gonadal steroid hormones (Berg, Tymoczko and Stryer, 2002; Lecerf and de Lorgeril, 2011), and thus is needed by the human body. When dietary cholesterol intake is low, the human body is capable of synthesizing cholesterol to maintain constant levels of cholesterol. Although altering the diet may reduce the cholesterol level in some people, dietary changes alone rarely

[44] Composition of milk from other species is detailed in Chapter 3.

lower cholesterol levels enough to change a person's risk of CVD from a high-risk category to a lower risk category.[45] Parodi (2009) examined the risk factors for CHD with emphasis on total- and LDL-cholesterol levels and reported that epidemiological studies do not supply convincing evidence for an association between SFA intake and CHD risk. The author concludes that the evidence "that shows the major cholesterol-raising SFA, C12:0, C14:0 and C16:0 concomitantly elevate antiatherogenic high-density lipoprotein (HDL)-cholesterol levels". Overall, the effect of SFA on serum lipoproteins suggests that they may be "atherogenically neutral" (Parodi, 2009). Similarly, Lecerf and de Lorgeril (2011) reported that epidemiological data do not support a link between dietary cholesterol and CVD, but the authors also remarked that there is an absence of clinical trial data and there are limitations to the epidemiological approach. As aptly stated by Astrup *et al.* (2011), "the effect of diet on a single biomarker is insufficient evidence to assess CHD risk. The combination of multiple biomarkers and the use of clinical endpoints could help substantiate the effects on CHD". Furthermore, the effect of particular foods on CHD cannot be predicted solely by their fatty-acid profile and the content of total SFAs, as individual SFAs may have different cardiovascular effects.

Conjugated linoleic acid

Conjugated linoleic acid (CLA) refers to a family of positional and geometric isomers of linoleic acid (an n-6 omega fatty acid) predominantly found in the milk and meat of ruminants. There are opposing opinions on its classification as a *trans* fat. For labelling purposes, the United States Food and Drug Administration (FDA) and Codex Alimentarius exclude CLA from the definition of TFAs but the United States National Academy of Sciences Institute of Medicine includes all TFAs whether conjugated or non-conjugated (USDHHS and FDA, 2003; FAO and WHO, 2004).

While there are 28 different isomers, or types, of CLA, the *cis*-9, *trans*-11 isomer accounts for 75–90 percent of total milk-fat CLA (Stanton *et al*., 2003), while *trans*-10, *cis*-12 CLA accounts for a much smaller proportion. These isomers have been linked to health-promoting activities, including an ability to inhibit various types of cancer, hypertension, atherosclerosis and diabetes and improve immune function and body composition (Pariza, Park and Cook, 2001; Nagao and Yanagita, 2005; Beppu *et al.,* 2006; Bhattacharya *et al.,* 2006; Kelley, Hubbard and Erickson, 2007; Silveira *et al.,* 2007; Watras *et al.,* 2007; Mitchell and McLeod, 2008; Benjamin and Spener, 2009; Churruca, Fernández-Quintela and Portillo, 2009). However, the proposed beneficial health effects of CLA are mostly derived from animal studies. McCrorie *et al.* (2011) recently reviewed the scientific evidence available for human health effects and found that three human studies that involved consuming CLA-enriched dairy products reported no effect on body weight or body mass index (BMI).

In an intervention study, *cis*-9, *trans*-11 was shown to modestly improve blood lipid profiles in healthy normolipidemic males (Tricon *et al.,* 2004). In another study

[45] The relationship between milk and dairy consumption and CVD is discussed in detail in Chapter 4.

in healthy males, consumption of this CLA isomer failed to lower LDL-cholesterol when consumed in amounts exceeding that currently present in dairy foods (Tricon *et al.,* 2006). Furthermore, the anti-atherosclerotic effects of CLA demonstrated in animal studies may not be the result of its effect on lipids, but rather may be related to another mechanism, for example an anti-inflammatory effect (McCrorie *et al.,* 2011). Similarly, the anti-diabetic properties of CLA cannot be fully determined from current epidemiological evidence, considering that few studies undertook rigorous measures of insulin resistance. Combined with small sample sizes and other study limitations, overall results show no effect of CLA on glucose and insulin (McCrorie *et al.,* 2011). Studies on animal models have shown that CLA has anti-inflammatory properties and may play a role in the management of chronic inflammation, such as inflammatory bowel disease and rheumatoid arthritis. However, similar to the other health outcomes described in this section, results from human studies investigating the effect of products that are naturally enriched with CLA on inflammation have been mixed (McCrorie *et al.,* 2011). The promising beneficial effects seen in some animal models have not yet been reflected in human studies. Indeed, FAO and WHO recently stated that there are insufficient data to provide a recommendation regarding CLA and cancers (FAO and WHO, 2010a).

Trans fatty acids

Ruminant *trans* fatty acids (rTFAs) are found naturally in dairy and meat products and are structurally different from industrial TFAs (iTFAs), which are predominantly a by-product of industrial processing, usually in the form of partially-hydrogenated vegetable oils (PHVO) (FAO and WHO, 2010a). Vaccenic acid constitutes the main TFA in milk fat and it can be partially converted into CLA in humans. In light of the potential health benefits of CLA, studies have attempted to increase vaccenic acid in milk fat (Cruz-Hernandez *et al.,* 2007, and references therein). The justification for this would need to be supported by conclusive evidence that CLA has a positive impact in humans and that vaccenic acid from ruminant sources is not a risk factor for CVD (Givens and Gibbs, 2008).

FAO and WHO (2010a) found convincing evidence that iTFA increases CHD risk factors and CHD events and probable evidence of an increased risk of fatal CHD, sudden cardiac death, metabolic syndrome and diabetes from iTFA. Similarly, Bendsen *et al.* (2011) recently concluded that iTFA may be positively related to CHD while rTFA may not be, although the authors note that it is not feasible to make a firm conclusion based on current evidence. In relation to cancer, FAO and WHO (2010a) stated that "there is not a large body of evidence to suggest either a deleterious or a beneficial effect of *trans* fats on cancers" but there is a possible increased risk of prostate cancer.

The quantity of *trans* fats consumed may also be a factor in the disease risk. Present knowledge on TFA intakes in most countries is not robust. Estimates of the intake of TFAs are generally obtained from dietary assessment surveys and the use of food composition tables which may have incomplete TFA data (Stender, Astrup and Dyerberg, 2008; Uauy *et al.,* 2009). There are large variations in the TFA content of snack and convenience foods (FAO and WHO, 2010a). The concentration of TFAs in ruminant fats varies with season and animal feed. The total intake of TFAs was investigated in the Transfair study in a number of European

countries in 1996 and the average daily intake varied from about 1.5 g in Greece and Italy to 5.4 g in Iceland (Stender, Astrup and Dyerberg, 2008, and references therein). FAO and WHO (2010a) reported that "in adults, the estimated average daily ruminant TFA intake in the US is about 1.5 g for men and 0.9 g for women. Average intake for both men and women, is 1.2 g, which corresponds to 0.5 % E". Considering these variations, estimates of TFA intake should be interpreted with caution (Stender, Astrup and Dyerberg, 2008). Mozaffarian, Aro and Willett (2009), who reviewed the evidence for effects of TFA consumption on CHD, found that the evidence from observational studies suggests that higher CHD risk is related to iTFA consumption rather than rTFA. "Because ruminant fat contains low levels of TFA (usually <6 percent of fatty acids), the quantities of ruminant TFA consumed were low in most of the populations studied (generally <1.0 percent E). Thus, even when total ruminant fat intake is relatively high, the potential amount of TFA from this source is still quite modest. These data do not discount the possibility that much higher amounts of ruminant fat could have adverse effects, but in the amounts consumed in actual diets rTFA do not appear to be major contributors to CHD risk". The authors also remark that, at amounts currently consumed, rTFA do not have detectable adverse relationships with disease risk but further investigation is warranted. At the present time, both sources of TFAs, and especially specific TFA isomers, should be considered when assessing effects on disease risk (Mozaffarian, Aro and Willett, 2009). FAO and WHO (2010a) also reported that there is convincing evidence that iTFAs increase CHD risk factors and that the estimated average daily rTFA intake among adults in most countries is low.

These conclusions are important when developing national nutritional policies and guidelines to reduce TFA intake. FAO and WHO (2010a) retained the recommendation of a total TFA intake of less than one percent of energy, which was based on the conclusions and published reports of the WHO Scientific Update on Trans Fatty Acid (Nishida and Uauy, 2009).

Many expert groups and public health authorities promote the removal of iTFA from the food supply and replacement with *cis*-unsaturated fats from vegetable oils rather than saturated fats from animal fats (FAO and WHO, 2010a; Skeaff, 2009). Efforts to reduce TFA contents of diets have primarily involved nutritional labelling of TFA content in foods and/or legislation to limit the use of PHVO in the manufacture of processed foods. Canada, Europe and the United States have enacted labelling requirements for TFA content, but the labelling thresholds and the TFA definitions differ between countries. Canadian and United States legislation require a declaration on foods. The FDA requires that the *trans* fat content need not be listed if the total fat is less than 0.5 g in one serving. Regulations in Denmark restrict the use of oils and fats that exceed 2 g of TFA /100 g in the manufacture of processed foods, with rTFAs being exempt from this ruling (FAO and WHO, 2010a). If similar legislation is implemented widely, the contribution of iTFAs to TFA intake may decline and ruminant foods may become the predominant source of TFAs in the diet. Further clinical studies are warranted to determine the effects on human health of consuming relatively higher quantities of rTFAs (L'Abbé *et al*., 2009; Mozaffarian, Aro and Willett, 2009).

n-3 fatty acids

n-3 fatty acids are essential for normal physiological functioning and for the maintenance of health. There is convincing evidence that replacing SFAs with PUFAs decreases the risk of CHD and possible evidence that PUFA intake can reduce diabetes risk (FAO and WHO, 2010a). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are two important long-chain n-3 PUFAs that may contribute to the prevention of CHD as well as possibly other degenerative diseases of aging (FAO and WHO, 2010a). Although humans have the capacity to convert α-linolenic acid (ALA) to EPA and DHA, the efficiency of conversion is low. Hence, EPA and DHA need to be provided in the diet. Fish and fish oils are rich sources of n-3 LC-PUFAs (Givens and Gibbs, 2008; FAO and WHO, 2010a). Efforts have been made to increase n-3 PUFAs in milk fat using animal feed strategies (Gebauer *et al.,* 2006). Modest increases in EPA and DHA in cow milk can be achieved through the addition of fish oil or fish by-products to the cows' diet but there is a risk of increasing the rTFA content (Givens and Gibbs, 2008; Bauman and Lock, 2010). Adding ALA in the form of plant oils and oilseeds has had little effect on EPA and DHA levels, possibly due to limited desaturase activity in the mammary gland of the dairy cow (Bauman and Lock, 2010). Another approach is to directly fortify milk with fish oils (further examined in Section 5.3.2).

5.2.2 Milk protein and health

The major proteins found in milk are casein and whey proteins, with casein (α_{s1}-, α_{s2}-, β-, and κ-casein) accounting for approximately 78 percent of the protein in cow milk and whey proteins accounting for about 17 percent of the total protein. The main whey proteins are β-lactoglobulin, α-lactalbumin, serum albumin, immunoglobulins and glycomacropeptide; minor proteins include lactoferrin, insulin growth factor (IGF) and the lactoperoxidase system. As discussed in Chapter 3, milk proteins vary according to the source of the milk; for example, the ratio of whey to casein is higher in human milk and equine milk (60:40) than in cow milk (20:80) (Mølgaard *et al.,* 2011).

Milk is considered to be an excellent source of essential amino acids for human nutrition, growth, and development (Kanwar *et al.,* 2009). Milk protein has a high protein-digestibility-corrected amino acid score (PDCAAS) and the protein fraction contains peptides and other bioactive factors that may have specific effects on growth and recovery from undernutrition (Michaelsen *et al.,* 2011). The impact of milk protein intake on body composition has not been fully elucidated, particularly at different life stages. Although some studies have reported that whey proteins and bioactive peptides in dairy may contribute to weight management, the evidence is contradictory. Cow-milk allergy (CMA) is probably the most serious issue associated with consumption of cow-milk protein and is generally diagnosed in children, although most children out-grow the condition by five years of age (Monaci *et al.*, 2006).[46]

[46] The association between dairy proteins and growth and development, weight management and milk protein allergy is discussed in detail in Chapter 4.

Major proteins: casein and whey

Casein, the predominant milk-protein component, is widely accepted to be a valuable source of amino acids for human growth. Traditionally, whey was considered the low-value by-product of cheese production, but in recent decades, whey components have attracted increasing commercial interest (Bulut Solak and Akin, 2012). Whey is the soluble fraction of milk that is separated from casein during cheese-making and casein manufacture in the dairy industry. The whey fraction contains a variety of proteins which can be separated by processes such as ultrafiltration and reverse osmosis to produce whey-protein concentrates. Whey proteins can be consumed as nutrition bars, powdered beverages or sports meals (Korhonen, 2009a; Hernández-Ledesma, Ramos and Gómez-Ruiz, 2011). Whey proteins, in addition to delivering amino acids, are reported to be involved in protection against infections, immune enhancement and development of the gut (Kanwar *et al.,* 2009), as well as being a source of bioactive peptides. Some reports suggest that the whey-protein complex is implicated in satiety and weight management, although it is not clear whether whey protein has a greater effect than other milk proteins in this regard (Korhonen, 2009a; Hernández-Ledesma, Ramos and Gómez-Ruiz, 2011; Mølgaard *et al.,* 2011).

α-lactalbumin, the predominant whey protein in human milk, is important in lactose synthesis. It has low immunogenicity, in contrast to β-lactoglobulin, which has been implicated in CMA. Recently, it has been suggested that it may have beneficial effects on sleep, mood and cognition because of its role in increasing serotonin levels (Korhonen, 2009a; Camfield *et al*., 2011). A number of health characteristics have been suggested for β-lactoglobulin, including antiviral and anticarcinogenic effects (Chatterton *et al.,* 2006). Lactoferrin, an iron-binding whey protein, has been associated with positive antimicrobial effects, immune modulation and modulation of the gut microbiota (Kanwar *et al.,* 2009; Tomita *et al.,* 2009, Nagpal *et al.,* 2012). A recent meta-analysis on the efficacy of lactoferrin in the eradication of *Helicobacter pylori* infection concluded that lactoferrin may have the potential to reduce *H. pylori* infection without adverse effects (Sachdeva and Nagpal, 2009). *Heliobacter pylori* is the causative agent of peptic ulcer diseases and chronic gastritis and is an important risk factor for development of gastric cancer (Salih, 2009); the global prevalence of *H. pylori* infection is more than 50 percent, mainly in developing countries.

Excessive protein consumption may have adverse human health effects. The rate at which the gastrointestinal tract can absorb amino acids and the liver's capacity to deaminate proteins and produce urea to excrete excess nitrogen are key issues. The safety and validity of increased protein intakes for both weight maintenance and muscle synthesis have been subjects of considerable debate and some health professionals, media and diet books advise consuming diets high in protein despite the lack of scientific data on the safety of increasing protein consumption (Bilsborough and Mann, 2006).

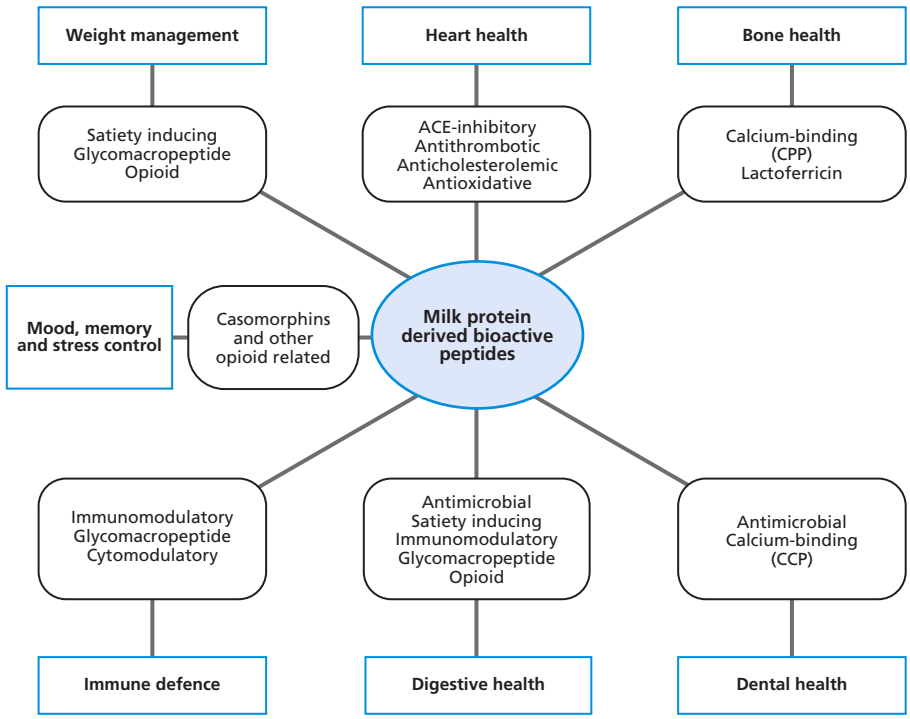
Protein fragments: bioactive peptides

Recent research has shown that milk proteins can act as precursors of bioactive peptides, which are protein fragments varying in size from two to 20 amino acids. These discrete amino-acid sequences are inactive within the parent protein molecule and can be released through the action of digestive proteases or via proteolytic enzymes,

as occurs during fermentation. Although research indicates that the peptides can exert a range of biological activities, depending on the amino-acid sequence, their physiological impact in humans is still unclear (Silva and Malcata, 2005; Nagpal *et al.*, 2012). Possible health benefits of milk-protein-derived bioactive peptides are presented in Figure 5.1.

Although the potential health benefits of bioactive peptides have attracted increasing interest in recent years, there are also reports suggesting that food-derived peptides may have a negative effect on human health (EFSA, 2009a). Following the review of scientific evidence of the relationship of β-casomorphin-7 (BCM7), a peptide sequence present in the milk protein β-casein with non-communicable diseases (NCDs) such as autism, CVD and type 1 diabetes, the European Food Safety Authority (EFSA) (2009a) concluded that "a cause-effect relationship between the oral intake of BCM7 or related peptides and aetiology or course of any suggested NCDs cannot be established".

FIGURE 5.1
Functionality of milk protein-derived bioactive peptides and their potential health targets



Source: Korhonen, 2009b.

5.2.3 Lactose

Lactose, a disaccharide formed from glucose and galactose, is the principal carbohydrate in milk; cow milk contains approximately 5 g of lactose/100 g. As well as providing energy, lactose (along with milk oligosaccharides) supports growth, aids in softening of stools and enhances water, sodium and calcium absorption (Hernández-Ledesma, Ramos and Gómez-Ruiz, 2011). As discussed in Chapter 4, lactose intolerance, which is caused by insufficient amounts or activity of lactase in the human intestine, can result in varying degrees of abdominal discomfort, bloating, diarrhoea and flatulence (Wilt *et al.,* 2010).

5.2.4 Dairy ingredients

In recent decades, technological and research advances have enabled the dairy industry to extract and modify dairy components into ingredients. A wide array of dairy ingredients is commercially available. Such ingredients are predominantly used in dairy foods. They are also found in bakery products, beverages, confectionery, dressings, sauces, cereals and sports beverages. Edible lactose is often used in foods such as bread, confectionaries and infant formula, as well as in non-food applications such as animal feed and fermentation-culture media. Casein-derived peptides have been used in pharmaceutical preparations and as dietary supplements (Nagpal *et al*., 2012).

Dairy ingredients can be used as processing aids in the manufacture of food. As defined by CODEX Alimentarius, a "processing aid means any substance or material, not including apparatus or utensils and not consumed as a food ingredient by itself, intentionally used in the processing of raw materials, foods or its ingredients, to fulfil a certain technological purpose during treatment or processing and which may result in the non-intentional but unavoidable presence of residues or derivatives in the final product". (FAO and WHO, 2010b). However, caution must be taken in labelling the final product as trace dairy ingredients may be present in the final product. This is significant for components such as cow-milk protein that can cause an adverse allergic reaction in susceptible consumers. It is imperative that any associated risks with a dairy component are fully understood and communicated to the consumer. In order to achieve a high level of protection for food-allergic consumers, allergens such as cow-milk protein should be indicated on the label of food products and alcoholic beverages such as wine; cow milk and/or its derivatives may be used as processing aids in wine-making and traces may remain in the final product (Kirschner *et al*., 2009). Recently, the EFSA released a scientific opinion from the International Organisation of Vine and Wine (OIV) related to the use of casein, caseinates and milk products as clarification processing aids[47] during the manufacture of wine, which concluded that wines fined using these substances may trigger an adverse reaction in susceptible individuals and the casein detection techniques as proposed by OIV were insufficient to eliminate the risk (EFSA, 2011).

[47] Clarification or fining of wines serves to remove insoluble and colloidal substances and astringent compounds such as tannins from wine. Fining/clarification agents/aids that are commonly used include casein from cow milk, fish gelatin and albumin and lysozyme (extracted from hens' eggs) (Kirschner *et al.*, 2009).

5.3 DAIRY PRODUCTS

In recent decades, technological advances have supported the development of new dairy-based products. Although processes such as fermentation have been traditionally used, the dairy sector has developed techniques to produce a diverse range of milk-based products and dairy ingredients.[48] It is now possible to remove specific dairy components for consumers with special dietary needs and specific intolerances. For example, lactose can be removed by hydrolysis or by physical means such as ultrafiltration and chromatography. It is also possible to enrich and fortify dairy products with nutrients such as iron, plant sterols and stanols. Broadly, dairy products can be categorized as basic products, such as fermented milk, cheese and yoghurt, and value-added products, such as low-fat and fortified milks (Nagpal *et al.,* 2012). Some of the health implications associated with fermented and fortified dairy products are outlined in the next section.

5.3.1 Fermented dairy products

Much has been written on the nutritional and therapeutic properties of fermented dairy products. Milk fermentation is one of the oldest known food preservation techniques, and involves the transformation of liquid milk into a range of value-added products by growth of micro-organisms in the milk and/or their activities on milk. Micro-organisms that perform the fermentation process may produce beneficial metabolites (biogenic effect) or may themselves interact with the host in a positive manner (the probiotic effect) (Stanton *et al*., 2005; Roupas, Williams and Margetts, 2009). The probiotic concept[49] was first introduced in the early 1900s by Russian scientist Elie Metchnikoff of the Pasteur Institute, who hypothesized that the presence of lactose-fermenting bacteria in the colon could prolong life (Metchnikoff, 1908; Candy *et al.,* 2008).

Fermented milk products have traditionally been associated with a series of health-promoting properties. In Eastern Europe, the fermented dairy product kephir has a long history of purported health benefits (Ribeiro and Ribeiro, 2010). The Maasai, a Nilo-Hamitic tribe living a nomadic life in the East African Rift Valley of Southern Kenya and Northern Tanzania, consume *kule naoto*, a traditional fermented milk product (Mathara *et al.,* 2004). The Maasai believe that *kule naoto* offers protection against ailments such as diarrhoea and constipation, but this has yet to be confirmed scientifically (Mathara, 1999). Fermented camel milk has received attention for its potential medicinal qualities, including the treatment of stomach ulcers, liver disorders, constipation and wounds (El-Agamy, 2009). *Shubat*, a fermented camel milk, is used as a therapeutic agent to treat tuberculosis in India, Libya and Kazakhstan (El-Agamy, 2009, and references therein). Systematic reviews of individual fermented dairy foods at the population level are however, lacking.

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[48] Liquid milk refers to whole milk, reduced-fat and fat-free milk, while a milk product is "any product obtained by any processing of milk, which may contain food additives, and other ingredients functionally necessary for the processing" (FAO and WHO, 2007).

[49] Probiotics are "live micro-organisms, which when administrated in adequate amounts, confer a health benefit on the host" (FAO and WHO, 2001).

Fermented milk products may be better tolerated by people with lactose intolerance, primarily because they contain less lactose (Panesar, 2011). In particular, yoghurt containing live bacteria may be better tolerated by lactose malabsorbers because of the β-galactosidase in the yoghurt or the presence of bacteria in the yoghurt that produce β-galactosidase in the small intestine. Furthermore, yoghurt takes longer to pass through the digestive system than does milk, thus allowing more effective breakdown of lactose (Buttriss, 1997).

Lactic acid bacteria (LAB) in fermented milks can affect food-borne pathogens. In Zimbabwe, LAB cultures isolated from naturally fermented milk (*amasi*) were shown to inhibit the survival and growth of the human pathogens *Escherichia coli* and *Salmonella enteriditis* (Mufandaedza *et al.,* 2006). In a study from Tibet, the bacteriocins produced by the LAB strains from kurut, a fermented milk, showed antimicrobial activity and were resistant to high temperatures (Luo *et al.,* 2011). However, the authors also remarked that "further research is necessary to purify the bacteriocins and study their detailed characters before its application in food fermentation" (Luo *et al.,* 2011).

St-Onge, Farnworth and Jones (2000) reported that "existing evidence from animal and human studies suggests a moderate cholesterol-lowering action of fermented dairy products", while Kiessling, Schneider and Jahreis (2002) demonstrated that daily consumption of fermented milk products for six months increased serum HDL-cholesterol, and improved the LDL/HDL ratio in women. Andrade and Borges (2009) examined the effect of milk fermented with *Lactobacillus acidophilus* and *Bifidobacterium longum* on plasma lipids of women with normal or moderately elevated cholesterol in a double-blind, cross-over study. Women with a baseline total cholesterol greater than 190 mg/dl who consumed the fermented milk showed a reduction in LDL-cholesterol. Other studies have explored the relationship between fermented milk consumption and hypertension. Usinger, Ibsen and Jensen (2009) reviewed human intervention studies of the possible antihypertensive effect of fermented milk and concluded that the "results are diverging, and the antihypertensive effect is still debatable". Usinger, Reimer and Ibsen (2012) concluded that fermented milk has no effect on blood pressure and that the results of the review "do not give notion to the use of fermented milk as treatment for hypertension or as a lifestyle intervention for pre-hypertension nor would it influence population blood pressure". Sonestedt *et al.* (2011) examined the association between the intake of milk, cheese, cream and butter and the incidence of CVD in the Swedish Malmo diet and cancer cohort. The milk was separated into fermented (yoghurt and cultured sour milk) and non-fermented milk. The authors reported that the highest intake category of fermented milk was associated with 15 percent (95 percent confidence interval: 5-24 percent; *P* trend=0.003) decreased incidence of CVD relative to the lowest intake category. However, such correlations from epidemiological studies do not demonstrate cause-effect relationships, hence caution is needed when interpreting epidemiological results.

Interestingly, it has been reported that yoghurt consumption can benefit vulnerable populations, including malnourished people and those with human immunodeficiency virus (HIV) (Solis *et al.,* 2002). Consumption of probiotic yoghurt was reported to improve gastrointestinal symptoms, nutritional intake and tolerance to antiretroviral treatment among a sample of people living with HIV in Mwanza,

Tanzania (Irvine, Hummelen and Hekmat, 2011). Data from the 24-hour dietary recall conducted during the study suggested that consumers of probiotic yoghurt had higher total energy and protein intakes and were more likely to achieve the recommended daily intakes of vitamin A, riboflavin, folate and calcium. However, the authors remarked that the results of this study need to be further substantiated because of limits imposed by the observational, retrospective study design (Irvine, Hummelen and Hekmat, 2011). Consumption of probiotic yoghurt was also associated with an increase in CD4 count[50] among consumers living with HIV in Tanzania (Irvine *et al.*, 2010). Dols *et al.* (2011), in a randomized double-blind study on the impact of probiotic yoghurt on HIV-positive women, found that yoghurt has the potential to transfer health benefits to the gut and participants revealed better appetite and less stomach gas. Anukam *et al.* (2008) suggested that yoghurt supplemented with *Lactobacillus rhamnosus* and *Lactobacillus reuteri* resolved moderate diarrhoea, flatulence and nausea in adult female patients with HIV/AIDS in Nigeria.

Reports suggest that some of the bacteria present in fermented milk products may cause adverse health effects. Enterococci are ubiquitous LAB that occur in fermented milk and dairy products. Some strains of enterococci are the subject of food safety concern[51] because of their ability to produce biogenic amines and the risk of transferring antibiotic resistance genes to intestinal microorganisms and food-associated pathogenic bacteria. Although low levels of biogenic amines are not considered to be a serious risk, they may have physiological and toxic effects when consumed in excessive amounts. Some strains of enterococci are opportunistic pathogens that may cause human disease (Mathur and Singh, 2005; Foulquié Moreno *et al.*, 2006; Jamaly *et al.*, 2010; Li *et al.*, 2011).

5.3.2 Fortified milk and dairy products

Food fortification has been defined as "the practice of deliberately increasing the content of an essential micronutrient, i.e. vitamins and minerals (including trace elements) in a food, so as to improve the nutritional quality of the food supply and provide a public health benefit with minimal risk to health" (WHO and FAO, 2006). Fortification has a long history of use in developed countries to address deficiencies of vitamins A and D and several B vitamins (thiamine, riboflavin and niacin), iodine and iron, and milk is an effective delivery vehicle of fat-soluble vitamins and minerals (WHO and FAO, 2006).[52]

The virtual elimination of childhood rickets in Canada and the United States has been largely attributed to fortification of milk with vitamin D, a practice that commenced as far back as the 1930s (WHO and FAO, 2006). However, as discussed in Chapter 4 (Section 4.4.7), a recent resurgence of the disease has been recorded in a number of countries, particularly among older children and adolescents in communities of recent immigrants, possibly as a result of the combined effect of low dietary calcium intakes and vitamin D deficiency (Pettifor, 2008). High rates

[50] CD4 count is a measure of immunity and indicates the stage of HIV disease. Keeping CD4 count high can reduce complications of HIV disease.
[51] Food safety issues related to milk and dairy products are discussed in Chapter 6.
[52] Evidence from five selected fortified milk programmes are examined in Chapter 7.

of hypovitaminosis D have been reported in Canada and the United States and evidence from cross-sectional studies suggest that the mass fortification of milk with vitamin D has not achieved its objective in reducing this prevalence (Calvo, Whiting and Barton, 2004). A number of reasons have been suggested. The concentration of vitamin D may not be sufficient to increase the concentration of 25-hydroxyvitamin D in blood, and milk and dairy consumption may be decreasing (O'Mahony *et al.,* 2011). In particular, some ethnic groups, including Asian immigrants to the United Kingdom and African-Americans in the United States, both of which are at greater risk of vitamin D deficiencies possibly because of ethno-cultural, environmental and genetic factors, may consume less milk and dairy products than other groups (Shaw and Pal, 2002; Calvo, Whiting and Barton, 2004; Alemu and Varnam, 2012).

Studies suggest that milk enriched with plant sterols shows promise in terms of reducing CVD risk factors (Madsen, Jensen and Schmidt, 2007; Hansel *et al.,* 2007; Mannarino *et al.,* 2009; Bañuls *et al*., 2010). Plant sterols, such as β-sitosterol and campesterol, are naturally occurring compounds that are found in all foods of plant origin, including vegetable oils, nuts, cereal grains and legumes. Plant sterols are reported to reduce the plasma level of LDL-cholesterol but the precise mechanism of action is not fully understood (Rudkowska, 2010). Although plant sterols/stanols have received acceptance by the European Union (EU) (EFSA, 2009b) and FDA (FDA, 2009), discussions are ongoing regarding the risk of overdosing with these ingredients, and their use is limited in industry. JECFA (2009) concurred with EFSA (2009b): "In general there seems so far to be little over-consumption of food products with added plant sterols, rather some consumers don't eat enough of the products to gain a real benefit. Modelling showed that consumption on more than three occasions per day or daily consumption of two or more products each at their respective recommended intake level was necessary to exceed a daily intake of 3 grams of plant sterols" (JECFA, 2009). FDA recommends a therapeutic phytosterol dose of 2–3 g/day and that plant sterols and stanol intakes should not exceed 3 g/day. "The dose above 3 g/day is not advised for a lack of considerably increased hypocholesterolemic effect and the threat of side-effects as a result of interfering with the absorption of fat-soluble vitamins, mostly β-carotene" (Bartnikowska, 2009).

Multiple micronutrient fortification

Fortification with multiple micronutrients has demonstrated positive results amongst different subgroups. A positive nutritional impact has been reported from adding vitamin C (ascorbic acid) to iron to enhance iron absorption. For example, in Chile, milk fortified with iron and vitamin C was found to reduce the prevalence of anaemia in infants and young children (WHO and FAO, 2006). A fermented-milk beverage supplemented with iron (3 mg iron/80 ml) and containing *Lactobacillus acidophilus* was found to increase nutrient intake and improve the nutritional status of preschool children in Brazil (Silva *et al*., 2008). Indeed, the absorption of iron appears to be enhanced by fermentation, presumably because of the presence of organic acids, including lactic acid (Özer and Kirmaci, 2010). A study of Indonesian children aged 6–59 months demonstrated that those receiving fortified milk were less likely to be anaemic than those receiving fortified noodles (Semba *et al.,* 2010). Iron-fortified milk was deemed to be effective at reducing the rates of anaemia in Mexican children aged 10–30 months (Villalpando *et al*., 2006; Rivera *et al.,* 2010).

Milk fortified with micronutrients was also found to be effective for improving iron status, anaemia and growth among 1–4-year-old children in India (Sazawal *et al.*, 2010). Muthayya *et al.* (2009) examined the effect of two different concentrations of a combination of micronutrients and n-3 fatty acids on growth and cognitive performance in low-income, marginally nourished Indian children. The delivery foods were wheat biscuit and a drink made from flavoured milk powder. The study concluded that high micronutrient treatment was more beneficial for linear growth, but no significant differences were found for overall cognitive performance.

National and international authorities recommend daily intakes of 200–650 mg of EPA and DHA based on the inverse relationship observed between CVD risk and consumption of these fatty acids (WHO, 2003; EFSA, 2005). However, in countries with a predominantly Western diet, average fish intake is below the recommended two or three servings per week (Kolanowski and Weixbrodt, 2007). Over the past decade, milk fortified with n-3 LC-PUFA (EPA and DHA) has been commercially available in several countries (Givens and Gibbs, 2008). Lopez-Huertas (2010) reviewed the results from nine controlled human intervention studies describing the effects of n-3 enriched milk on health. The results suggested that consumption of such milk (in the context of a balanced diet and healthy lifestyle) improved blood lipid profiles by reducing mainly cholesterol, LDL-cholesterol and triglycerides (Lopez-Huertas, 2010).

5.4 FROM TRADITIONAL TO MODERN DAIRY FOODS

The nature of dairy products has changed dramatically in recent decades, with an increased orientation towards the production of "value added products", some of which are segmented into the "health and wellness" market. According to Euromonitor International, this sector accounts for one-third of the US$300 billion global dairy market (GRAIN, 2011). During the 1990s in particular, the dairy industry started to produce differentiated products that are marketed to improve health and wellbeing (Nagpal *et al.*, 2012). Such products are often commercially termed as "functional" and may contain, for example, bioactive components (lactose, whey proteins) and/or peptides. A multitude of factors underpin the innovation of "health enhancing" dairy foods, such as changing diets, demographic shifts, increasing prevalence of diet-related diseases, consumer awareness of health issues, innovation in food science and technology and health-related research. Arguably, the main driving factor for the dairy industry is to develop products that will have a market advantage (Roupas, Williams and Margetts, 2009).

The influence of dietary recommendations on dairy product innovation can be traced to the 1980s when there was a major shift towards fat-reduced or fat-free alternatives. Around this time, the change in United States dietary recommendations to avoid excessive fat, especially saturated fat and cholesterol, led to the increased popularity of reduced-fat and skimmed milk. As discussed in Chapter 4, many developed countries currently recommend low-fat milk and dairy. These recommendations are now being adopted by some middle- and low-income countries where dietary patterns are being "westernized" and rates of overweight and obesity are rising rapidly along with increased rates of NCDs. Dairy products such as yoghurt that are marketed as "low fat" or "natural" are frequently seen by consumers as a healthy alternative to full-fat varieties, but many of these products are high

in calories because sugar is substituted for fat in them. This means that some low-fat yoghurts can contain more calories than the full-fat varieties, making them a poorer food choice than consumers are led to believe. This is not to imply that recommendations for dietary changes should not be made, but, as discussed in Chapter 4, it is imperative to consider the impact of nutrient reduction on the diet as a whole (Maziak, Ward and Stockton, 2008).

In recent times, innovations in dairy products have expanded beyond low-fat milk to encompass dairy ingredients, flavoured milks and drinking yoghurts enriched with multiple nutrients. Recent innovative food products have received mixed response but the willingness of the consumer to adopt or reject such products is critical to their success (de Barcellos *et al*., 2009). As noted by Falguera, Aliguer and Falguera (2012) "many of the innovative products have failed…the majority of people are unsure of their benefits…and consumers tend to prefer food products that bring a simple but clear health benefit and even those that are more concerned about health issues perceive products that are intrinsically healthy as preferable".

5.4.1 Regulatory health and nutrition claim framework and recent legislative developments

Consumers use nutrition labelling to make an informed food choice. It is therefore critical that the regulatory framework on labelling ensures that the consumer receives accurate information and provides protection from misleading nutrition and health claims (Capacci *et al.,* 2012). Codex Alimentarius has developed global standards and guidelines on food labelling. National regulations still vary and international trade has meant that dairy companies may be required to adhere to a number of regulations. In particular, the subject of health and nutrition claims has received considerable attention from both industry and the regulators. The approach to the use of health claims may differ around the world but a common theme is that any claim must be substantiated by scientific evidence. The general consensus amongst legislators is that the regulatory framework should protect the consumer from false information, promote fair trade and encourage innovation in the food industry that can ultimately translate into healthier lifestyles (Roupas, Williams and Margetts, 2009). Codex Alimentarius defines a health claim as "any representation that states, suggests, or implies that a relationship exists between a food or a constituent of that food and health"; in other words, it is any statement used on labels, in marketing or advertising that states or implies a health benefit can result from consuming a food or food components. Some examples of these are given in Table 5.1.

Legislation concerning health and nutrition claims has progressed slowly in many countries (Roupas, Williams and Margetts, 2009). The debate over the validity of health claims has been particularly active in Europe and the EU framework now includes regulations (Reg. No. 1924/2006; Reg. No. 1925/2006) on the use of nutrition claims (such as "low fat" or "no added sugar") and health claims (such as "reduces blood cholesterol"). Scientifically sound evidence is fundamental to the approval and overall credibility of a claim, with particular reference to randomized, placebo-controlled intervention studies in humans. As part of these regulations, EFSA is responsible for evaluating the scientific evidence for any claims. Between 2008 and 2011, approximately 3 000 food-related generic (Article 13) health claims were assessed and 443 scientific opinions were released, with the vast majority of

TABLE 5.1
Types and examples of nutrition and health claims

Health claims		
Nutrient function claim	**Other function claims**	**Reduction of disease risk claims**
A nutrition claim that describes the physiological role of the nutrient in growth, development and normal functions of the body.	These claims concern specific beneficial effects of the consumption of foods or their constituents, in the context of the total diet, on normal function or biological activities of the body.	Claims relating the consumption of a food or food constituent, in the context of the total diet, to the reduced risk of developing a disease or health-related condition. Risk reduction means significantly altering a major risk factor(s) for a disease or health-related condition.
Example: Substance A (naming a physiological role of nutrient A in the body in the maintenance of health and promotion of normal growth and development). Food X is a source of/high in nutrient A. For example, relates to the growth, development and functions of the body, refers to psychological and behavioural functions, slimming or weight control. For example, calcium is needed for normal growth and development of children.	Example: Substance A (naming the effect of substance A on improving or modifying a physiological function or biological activity associated with health). Food Y contains x grams of substance A.	Example: A healthful diet low in nutrient or substance A may reduce the risk of disease D. A healthful diet rich in nutrient or substance A may reduce the risk of disease D. Food X is low/high in nutrient or substance A. For example, plant sterols have shown to lower/reduce blood cholesterol. High cholesterol is a risk factor in the development of CHD.

Source: FAO and WHO, 2011.

recent applications being rejected. As of May 2012, 222 health claims have been officially approved by the European Commission (EC).

The EC Directorate General for Health and Consumers (DG SANCO) maintains a register of all the generic health claims assessed by EFSA for which the authorization procedure is finished (http://ec.europa.eu/nuhclaims/). Table 5.2 lists the authorised dairy-associated claims. Forty-three claims have been approved, 21 of which directly relate to nutrients that are naturally present in milk, i.e. calcium (8), calcium and vitamin D (1), phosphorus (5), protein (3), lactase enzyme (1), lactulose (1) and riboflavin (2). The other authorized claims refer to nutrients that can be added to milk and/or dairy products, such as iron, plant sterols and stanols and vitamin D.

How will health claims affect the consumer?

An objective of the EU health and nutrition claim regulations is to support the consumer in making an informed choice about their diet by ensuring that any claim made on food is fully substantiated and that the wording is understandable. Prior to the implementation of regulatory control, claims of many dairy products to be "more healthy" were not supported by robust data. It is possible that this has led to the current levels of consumer scepticism regarding claimed health benefits from food companies, where "consumers express concern that health claims are just another sales tool" (Roupas, Williams and Margetts, 2009, and references therein). Indeed, it is debatable whether labels and information used in advertising actually translate into improved food selection behaviour. The EC-funded Eatwell Project

recently published a review of 129 policy interventions to promote healthy eating. The report stated that "existing assessments of the impact of labelling on food intake do not show conclusive results in terms of healthier purchasing choices" (Capacci *et al*., 2012).

Complex, over-scientific wording of the claims may also deter consumers. Singer *et al.* (2006) reported that splitting a claim (i.e. a brief claim at the front of a package directing consumers to the full health claim at the back) produced more positive responses.

How will health claims affect the dairy industry?

Another aim of the EU legislation is to provide food producers and manufacturers with clear, harmonized regulations and to support fair competition, where companies can market equally on a level playing field over a large common market, whilst also encouraging research and innovation based on science. Queries addressed to DG SANCO have raised concerns that small and medium-sized companies may not have the financial resources to conduct the necessary research that would support a claim. The posted response states that "they may use health claims approved through applications submitted by larger companies" provided that they "can demonstrate compliance with the conditions of use for the claims" (http://ec.europa.eu/food/food/labellingnutrition/claims/docs/20100503_collective_answer_en.pdf).

It would also appear that large multinationals are struggling to gain approval for their claims. In 2010, Danone withdrew health-claim applications for its Activia and Actimel yoghurts. Previously, Activia, which contains *Bifidobacterium* species, was marketed as having a positive effect on the digestive system and Actimel as being able to "reinforce an infant's immune system". The United Kingdom Advertising Standards Authority recently ruled that an advertisement for Actimel that claimed it "could support the defences of normal, healthy school-aged children against common, every day childhood infections" was misleading (EUbusiness, 2010; GRAIN, 2011). EFSA has also rejected applications from Yakult on probiotics where there was inconclusive evidence regarding the cause-and-effect relationship between *Lactobacillus casei* Shirota and the maintenance of defences against upper respiratory tract infections via a boosted immune system. Interestingly, EFSA have not accepted any of the health claims attributed to probiotic cultures. The rejections of these claims stem from insufficient characterization of probiotic strains or poor substantiation of cause-and-effect links (Guarner *et al.,* 2011).

5.5 CONCLUSIONS

Social and technological developments of the past few decades have significantly influenced the variety of dairy products available. In this chapter we have presented some of the main components that can be altered during processes such as fermentation and fortification. Dairy foods and their nutrients are not consumed in isolation and no single food can supply all essential nutrients. When investigating the relationship between dairy products and health, it is important to consider that the human diet is complex and is not defined by the inclusion or exclusion of one food, but is considered in totality (EUFIC, 1996; German *et al.,* 2009; Kliem and Givens, 2011). Although it is difficult to reach a firm conclusion about the health

impact of individual dairy products, in general, dairy can be consumed as part of a healthy, balanced diet.

Milk fat is highly complex, consisting of a large number of fatty acids and other lipid molecules that have a variety of effects on human health. The relationship between milk-fat intake and health impact is complex (German *et al.,* 2009). FAO and WHO (2010a) recommends that total intake of SFAs should not exceed 10 percent of energy and SFAs should be replaced with PUFAs to reduce the risk of CHD. At current intake levels, rTFA do not appear to be major contributors to CHD risk but further investigation is needed and both iTFA and rTFA should be considered when assessing disease risk (Mozaffarian, Aro and Willett, 2009). Milk is considered to be an excellent source of essential amino acids for human nutrition, growth and development (Kanwar *et al.,* 2009). Milk protein has a high PDCAAS and the protein fraction contains peptides and other bioactive factors that may have specific effects on growth and recovery from undernutrition (Michaelsen *et al.,* 2011). Although bioactive peptides and other dairy ingredients such as CLA represent an opportunity for future research, consideration must be given to any potential adverse health effects.

Nutritional composition can be altered through fermentation and fortification. Fermented products have been linked with positive health outcomes and fortification of milk and dairy products have been shown to be a useful means of increasing nutrient intake and improving optimal nutrient status. It is now possible to remove specific dairy components, such as lactose and fat, for consumers with special dietary requirements and lactose intolerance.

Balance and variety is fundamental to healthy eating. Given the diversity of dairy products with differing compositions, ideally the consumer should be aware of the product's overall nutritional profile and how it can contribute positively or negatively to the diet. Today's consumers receive nutrition information and dietary advice on dairy consumption from a variety of sources. As illustrated in Chapter 4, many countries recommend low-fat milk and dairy products. These recommendations can be traced to the 1980s in the United States. The resulting demand for low-fat products provided an incentive to the dairy industry to develop new products and reformulate existing ones. However, some of the products advertised as low fat and "better for your health" may have higher sugar content. It is important to consider the impact of reduction of one nutrient on the food and the diet as a whole (Gibson, 1996; Maziak, Ward and Stockton, 2008).

Whether dairy products or components, such as whey or bioactive peptides, can offer an additional health benefit other than their nutritional value has not been consistently proved by scientific studies. To date, many products claimed as being "health-enhancing" lack the scientific evidence to merit claims. The subject of health and nutrition claims has received considerable attention from both industry and regulators. The general consensus amongst the legislators is that the regulatory framework should protect the consumer from false information, promote fair trade and encourage innovation in the food industry that can ultimately translate into healthier lifestyles (Roupas, Williams and Margetts, 2009). The debate over the validity of health claims has been particularly active in Europe, and the EU framework now includes regulations on the use of nutrition claims (such as "low fat" or "no added sugar") and health claims (such as "reduces blood cholesterol").

Scientifically sound evidence is fundamental to the approval and overall credibility of a claim.

The nexus between diet and health is complicated. Consumers have become increasingly aware of how dietary patterns can play a key role in the development and prevention of some chronic diseases (Lopez-Huertas, 2010) but struggle with conflicting health messages from both the public and private sectors (Cash, Wang and Goddard, 2005; Wansink and Chandon, 2006). The dairy industry can play an instrumental role in promoting lifelong healthy lifestyles by orientating research to produce nutrient-rich rather than energy-dense dairy foods and supporting the science that will fill the current knowledge gaps (Roupas, Williams and Margetts, 2009).

DISCLOSURE STATEMENT

The authors declare that no financial or other conflict of interest exists in relation to the content of the chapter.

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ANNEX

TABLE 5.2
EU register of dairy-related nutrition and health claims

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Calcium	Calcium contributes to normal blood clotting	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Blood coagulation	2009;7(9):1210	Authorized
Art.13(1)	Calcium	Calcium contributes to normal energy-yielding metabolism	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Energy-yielding metabolism	2009;7(9):1210	Authorized
Art.13(1)	Calcium	Calcium contributes to normal muscle function	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Muscle function and neurotransmission	2009;7(9):1210	Authorized
Art.13(1)	Calcium	Calcium contributes to normal neurotransmission	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Muscle function and neurotransmission	2009;7(9):1210	Authorized
Art.13(1)	Calcium	Calcium contributes to the normal function of digestive enzymes	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Function of digestive enzymes	2009;7(9):1210	Authorized
Art.13(1)	Calcium	Calcium has a role in the process of cell division and specialization	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Regulation of cell division and differentiation	2010;8(10):1725	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Calcium	Calcium is needed for the maintenance of normal bones	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of normal bones and teeth	2009;7(9):1210, 2009;7(9):1272, 2010;8(10):1725, 2011;9(6):2203	Authorized
Art.13(1)	Calcium	Calcium is needed for the maintenance of normal teeth	The claim may be used only for food which is at least a source of calcium as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of normal bones and teeth	2009;7(9):1210, 2010;8(10):1725, 2011;9(6):2203	Authorized
Art.13(1)	Protein	Protein contributes to a growth in muscle mass	The claim may be used only for food which is at least a source of protein as referred to in the claim SOURCE OF PROTEIN as listed in the Annex to Regulation (EC) No 1924/2006.	Growth or maintenance of muscle mass	2010;8(10):1811, 2011;9(6):2203	Authorized
Art.13(1)	Protein	Protein contributes to the maintenance of muscle mass	The claim may be used only for food which is at least a source of protein as referred to in the claim SOURCE OF PROTEIN as listed in the Annex to Regulation (EC) No 1924/2006.	Growth or maintenance of muscle mass	2010;8(10):1811, 2011;9(6):2203	Authorized
Art.13(1)	Protein	Protein contributes to the maintenance of normal bones	The claim may be used only for food which is at least a source of protein as referred to in the claim SOURCE OF PROTEIN as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of normal bones	2010;8(10):1811, 2011;9(6):2203	Authorized
Art.13(1)	Riboflavin (vitamin B_2)	Riboflavin contributes to normal energy-yielding metabolism	The claim may be used only for food which is at least a source of riboflavin as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Contribution to normal energy-yielding metabolism	2010;8(10):1814	Authorized
Art.13(1)	Riboflavin (vitamin B_2)	Riboflavin contributes to normal functioning of the nervous system	The claim may be used only for food which is at least a source of riboflavin as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of the normal function of the nervous system	2010;8(10):1814	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Phosphorus	Phosphorus contributes to normal energy-yielding metabolism	The claim may be used only for food which is at least a source of phosphorus as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Energy-yielding metabolism	2009;7(9):1219	Authorized
Art.13(1)	Phosphorus	Phosphorus contributes to normal function of cell membranes	The claim may be used only for food which is at least a source of phosphorus as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Function of cell membranes	2009;7(9):1219	Authorized
Art.13(1)	Phosphorus	Phosphorus contributes to the maintenance of normal bones	The claim may be used only for food which is at least a source of phosphorus as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of bone and teeth	2009;7(9):1219	Authorized
Art.13(1)	Phosphorus	Phosphorus contributes to the maintenance of normal teeth	The claim may be used only for food which is at least a source of phosphorus as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of bone and teeth	2009;7(9):1219	Authorized
Art.14(1)(b)	Phosphorus	Phosphorus is needed for the normal growth and development of bone in children	The claim can be used only for food which is at least a source of phosphorus as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation 1924/2006.		Q-2008-217	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Vitamin D	Vitamin D contributes to normal absorption/ utilization of calcium and phosphorus	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Absorption and utilization of calcium and phosphorus and maintenance of normal blood calcium concentrations	2009;7(9):1227	Authorized
Art.13(1)	Vitamin D	Vitamin D contributes to normal blood calcium levels	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Absorption and utilization of calcium and phosphorus and maintenance of normal blood calcium concentrations	2009;7(9):1227, 2011;9(6):2203	Authorized
Art.13(1)	Vitamin D	Vitamin D contributes to the maintenance of normal bones	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of bones and teeth	2009;7(9):1227, 2009;7(9):1272	Authorized
Art.13(1)	Vitamin D	Vitamin D contributes to the maintenance of normal muscle function	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Normal muscle function	2010;8(2):1468	Authorized
Art.13(1)	Vitamin D	Vitamin D contributes to the maintenance of normal teeth	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of bones and teeth	2009;7(9):1227	Authorized
Art.13(1)	Vitamin D	Vitamin D contributes to the normal function of the immune system	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Normal function of immune system and inflammation response	2010;8(2):1468	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Vitamin D	Vitamin D has a role in the process of cell division	The claim may be used only for food which is at least a source of vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Cell division	2009;7(9):1227	Authorized
Art.14(1)(b)	Vitamin D	Vitamin D is needed for normal growth and development of bone in children	The claim can be used only for food which is at least a source of Vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation 1924/2006.		Q-2008-323	Authorized
Art.14(1)(b)	Calcium and vitamin D	Calcium and vitamin D are needed for normal growth and development of bone in children	The claim can be used only for food which is at least a source of calcium and vitamin D as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/OR [NAME OF MINERAL/S] as listed in the Annex to Regulation 1924/2006.		Q-2008-116	Authorized
Art.13(1)	Lactase enzyme	Lactase enzyme improves lactose digestion in individuals who have difficulty digesting lactose	The claim may be used only for food supplements, with a minimum dose of 4500 FCC (Food Chemicals Codex) units with instructions to the target population to consume with each lactose containing meal. Information shall also be given to the target population that tolerance to lactose is variable and they should seek advice as to the role of this substance in their diet.	Breaking down lactose	2009;7(9):1236, 2011;9(6):2203	Authorized
Art.13(1)	Lactulose	Lactulose contributes to an acceleration of intestinal transit	The claim may be used only for food which contains 10 g of lactulose in a single quantified portion. In order to bear the claim, information shall be given to the consumer that the beneficial effect is obtained with a single serving of 10 g of lactulose per day.	Reduction in intestinal transit time	2010;8(10):1806	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Live yoghurt cultures	Live cultures in yoghurt or fermented milk improve lactose digestion of the product in individuals who have difficulty digesting lactose	In order to bear the claim, yoghurt or fermented milk should contain at least 108 Colony Forming Units live starter microorganisms (*Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*) per gram.	Improved lactose digestion	2010;8(10):1763	Authorized
Art.13(1)	Docosahexaenoic acid (DHA)	DHA contributes to maintenance of normal brain function	The claim may be used only for food which contains at least 40 mg of DHA per 100 g and per 100 kcal. In order to bear the claim information shall be given to the consumer that the beneficial effect is obtained with a daily intake of 250 mg of DHA.	Maintenance of normal brain function	2010;8(10):1734, 2011;9(4):2078	Authorized
Art.13(1)	Docosahexaenoic acid (DHA)	DHA contributes to the maintenance of normal vision	The claim may be used only for food which contains at least 40 mg of DHA per 100 g and per 100 kcal. In order to bear the claim information shall be given to the consumer that the beneficial effect is obtained with a daily intake of 250 mg of DHA.	Maintenance of normal vision	2010;8(10):1734, 2011;9(4):2078	Authorized
Art.13(1)	Eicosapentaenoic acid and docosahexaenoic acid (EPA/DHA)	EPA and DHA contribute to the normal function of the heart	The claim may be used only for food which is at least a source of EPA and DHA as referred to in the claim SOURCE OF OMEGA 3 FATTY ACIDS as listed in the Annex to Regulation (EC) No 1924/2006. In order to bear the claim information shall be given to the consumer that the beneficial effect is obtained with a daily intake of 250 mg of EPA and DHA.	Maintenance of normal cardiac function	2010;8(10):1796, 2011;9(4):2078	Authorized
Art.13(1)	Foods with a low or reduced content of saturated fatty acids	Reducing consumption of saturated fat contributes to the maintenance of normal blood cholesterol levels	The claim may be used only for food which is at least low in saturated fatty acids, as referred to in the claim LOW SATURATED FAT or reduced in saturated fatty acids as referred to in the claim REDUCED [NAME OF NUTRIENT] as listed in the Annex to Regulation (EC) No 1924/2006.	Maintenance of normal blood LDL-cholesterol concentrations	2011;9(4):2062	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Iron	Iron contributes to normal cognitive function	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Cognitive function	2009;7(9):1215	Authorized
Art.13(1)	Iron	Iron contributes to normal energy-yielding metabolism	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Contribution to normal energy-yielding metabolism	2009;7(9):1215, 2010;8(10):1740	Authorized
Art.13(1)	Iron	Iron contributes to normal formation of red blood cells and haemoglobin	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Formation of red blood cells and haemoglobin	2009;7(9):1215, 2010;8(10):1740	Authorized
Art.13(1)	Iron	Iron contributes to normal oxygen transport in the body	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Oxygen transport	2009;7(9):1215, 2010;8(10):1740	Authorized
Art.13(1)	Iron	Iron contributes to the normal function of the immune system	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Function of the immune system	2009;7(9):1215	Authorized
Art.13(1)	Iron	Iron contributes to the reduction of tiredness and fatigue	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Reduction of tiredness and fatigue	2010;8(10):1740	Authorized

TABLE 5.2 *(continued)*

Claim type	Nutrient, substance, food or food category	Claim	Conditions of use of the claim / Restrictions of use/ Reasons for non-authorization	Health relationship	EFSA opinion reference/ Journal reference	Status
Art.13(1)	Iron	Iron has a role in the process of cell division	The claim may be used only for food which is at least a source of iron as referred to in the claim SOURCE OF [NAME OF VITAMIN/S] AND/ OR [NAME OF MINERAL/S] as listed in the Annex to Regulation (EC) No 1924/2006.	Cell division	2009;7(9):1215	Authorized
Art.13(1)	Monounsaturated and/or polyunsaturated fatty acids	Replacing saturated fats with unsaturated fats in the diet contributes to the maintenance of normal blood cholesterol levels [MUFA and PUFA are unsaturated fats]	The claim may be used only for food which is high in unsaturated fatty acids, as referred to in the claim HIGH UNSATURATED FAT as listed in the Annex to Regulation (EC) No 1924/2006.	Replacement of mixtures of saturated fatty acids (SFAs) as present in foods or diets with mixtures of polyunsaturated fatty acids and maintenance of normal blood LDL-cholesterol concentrations	2011;9(4):2069, 2011;9(6):2203	Authorized
Art.13(1)	Plant sterols and plant stanols	Plant sterols/stanols contribute to the maintenance of normal blood cholesterol levels	In order to bear the claim information shall be given to the consumer that the beneficial effect is obtained with a daily intake of at least 0.8 g of plant sterols/stanols.	Maintenance of normal blood cholesterol concentrations	2010;8(10):1813, 2011;9(6):2203	Authorized

Source: Extracted from http://ec.europa.eu/nuhclaims

Chapter 6
Safety and quality

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ABSTRACT
This chapter addresses the safety and quality of milk and dairy products. Aspects related to safety are covered in detail while the discussion on quality is limited to essential quality and prevention of fraudulent practices and misleading information to consumers. The objective is to provide the reader with an understanding of the main food-safety hazards in milk, their sources and means of prevention. The reader will also gain a greater understanding of the different challenges faced by developed and developing/transition countries and risk factors affecting the safety of milk and dairy products in these different contexts. The chapter highlights the important role of the public sector and of all food-chain operators in ensuring the safety of the final product through a preventative approach along the food chain. Food-safety issues are discussed in the knowledge that risks associated with milk and dairy products can be greatly reduced if appropriate preventative measures are implemented. Official controls by government and international regulations governing the milk sector, including Codex Alimentarius standards and codes of practice are, also discussed. Topical and emerging issues in the milk and dairy sector are highlighted, including the safe use of veterinary medicinal products in animal husbandry, importance of traceability, safety of animal feeds and demand among certain consumers for unpasteurized milk.

Keywords: Milk, dairy products, contaminants, food safety, pasteurization, microorganisms, biological hazards, chemical hazards, risk analysis, GHPs, HACCP, Codex Alimentarius

6.1 INTRODUCTION
This chapter presents an overview of the risks to human health associated with the consumption of milk and dairy products, and discusses suitable controls and preventive measures to address them in the context of protection of consumer health and supporting economic development. Milk and dairy products are generally very rich in nutrients and thus provide an ideal growth environment for many microorganisms. This includes spoilage organisms in milk, some strains of which can survive pasteurization and grow at refrigeration temperatures. In addition, milk can be a potentially significant source of food-borne pathogens, the presence of which is determined by the health of the dairy herd, quality of the raw milk, milking and

pre-storage conditions, available storage facilities and technologies, and hygiene of the animals, environment and workers. Milk and dairy products can also contain chemical hazards and contaminants – mainly introduced through the environment, animal feedstuffs, animal husbandry and industry practices.

Although milk and dairy products can transmit biological and chemical hazards, there are effective control measures that can minimize risk to human health, key among which is pasteurization. Originally designed to ensure adequate destruction of common pathogenic micro-organisms (including *Mycobacterium bovis*, commonly responsible for tuberculosis at the time), pasteurization can extend the shelf-life of milk by destroying almost all yeasts, molds and common spoilage bacteria (Creamer *et al.*, 2002).

Minimizing health risks from milk and dairy products requires a continuous system of preventive measures starting with animal feed suppliers, through farmers and on-farm controls (including the prudent use of veterinary drugs), to milk processors and the application of good hygiene practices and food-safety management systems throughout the chain.

Food-safety risks at the point of consumption may vary between countries or areas within countries. Major differences occur between a largely industrialized dairy sector where pasteurization technologies are routinely applied and regulated and a dairy sector where there are many small-scale dairy farmers and milk may be sold through informal channels. The informal market, which handles much of the milk and dairy products in many countries, is characterized by unpasteurized milk sold through small-scale channels that lack a cold chain and have little or no regulatory control. In some cases there can be a cultural bias towards the consumption of raw milk. However, despite the differences, all countries, whether they have a structured industrialized dairy sector or unstructured informal sectors, should apply relevant food safety and animal health programmes, regulatory controls and monitoring and compliance systems to protect the health of their citizens.

The challenge to all food-safety policy-makers is to ensure that appropriate measures are taken to prevent food-borne illnesses and to support implementation of safe food practices (including hygiene) and education for dairy farmers, suppliers and consumers while at the same time promoting economic development of the dairy sector. Vulnerable consumer groups, particularly infants, pregnant women, immune-compromised individuals and the elderly, must be protected. Due regard should be given to all dairy products made available for human consumption, including both those produced and consumed locally and those traded on regional and global markets.

6.2 FOOD-SAFETY HAZARDS SPECIFIC TO MILK AND MILK PRODUCTS

A food-safety hazard is defined as "a biological, chemical or physical agent in a food, or condition of food with the potential to cause an adverse health effect" (FAO and WHO, 2003). The main risks to human health associated with milk and dairy products fall into three main categories: biological, chemical and physical (Table 6.1).

TABLE 6.1
Main food-safety hazards

Biological hazards	Chemical hazards	Physical hazards
Pathogenic bacteria (including toxin-producing bacteria)	Naturally occurring toxins	Metal fragments
Toxigenic moulds/fungi	Direct and indirect food additives	Bone fragments
Parasites	Pesticide residues	Glass pieces
Viruses	Veterinary drug residues	Insect parts/fragments
Other biological hazards	Heavy metals	Jewellery
	Environmental contaminants (e.g. dioxins)	Stones
	Chemical contaminants from packaging material	Hair
	Allergens	

Source: FAO, 2006.

6.2.1 Biological hazards

Milk and dairy products can harbour a variety of micro-organisms, including many zoonotic bacteria and some viruses (e.g. retroviruses and cytomegalovirus) (Kaufmann, Sher and Ahmed, 2002). The main pathogenic micro-organisms of concern and related control measures are given in Table 6.2.

Where an animal is healthy, the microbiological quality of milk at the time of milking is generally good; milk from the udder contains very few bacteria (although it may include human pathogens) and the natural inhibitory systems in milk prevent a significant rise in microbial cell counts for the first three or four hours at ambient temperatures (Jay, Loessner and Golden, 2005). Once milk is secreted from the udder, it can be contaminated from many sources (air, faeces, bedding material, soil, feed, water, equipment, animal hides and people). The prevalence of pathogens in milk is influenced by numerous factors such as farm size, number of animals on the farm, dairy herd health, hygiene in the dairy farm environment, farm management practices, geographic location and season (Oliver, Jayarao and Almeida, 2005).

In the past, the principal pathogens of concern in milk were *Mycobacterium bovis* (cause of bovine tuberculosis and a form of human tuberculosis), *Brucella abortus* (brucellosis) and *Coxiella burnettii* (Q fever). While these have been largely or entirely eliminated from the dairy herd in many countries they have remained endemic in many regions (Kazwala *et al.*, 1998; Zumárraga *et al.*, 2012). Furthermore, *M. bovis* is now re-emerging in some regions where it had previously been eliminated (Tenguria *et al.*, 2011). Food-borne pathogens associated with raw milk now of concern include *Campylobacter* spp., pathogenic strains of *Escherichia coli* (e.g. Shiga toxin -producing *E. coli* [STEC]), *Listeria monocytogenes*, *Staphylococcus aureus* and *Salmonella* spp. (Fox and Cogan, 2004). *Bacillus cereus, Yersinia enterocolitica* and *Cronobacter* spp. can also be of concern. Dairy cattle are a recognized reservoir of *Salmonella* spp., *Campylobacter* spp., *Clostridium* spp., STEC, *Cryptosporidium parvum, Brucella* spp. and *M. bovis* in certain countries. Other pathogens may contaminate the milk from external sources; for example, *Listeria* species are widespread in nature and live naturally in plants and the soil environment (Oliver, Jayarao and Almeida, 2005). *Listeria monocytogenes*, which can be

TABLE 6.2
Main pathogenic micro-organisms associated with milk and dairy products

Pathogen	Main source of infection	Main means of on-farm control	Main means of control in processing and food handling
Bacillus cereus	Via milk	No effective control measures presently available	Good manufacturing and hygiene practices. Holding cooked foods at either >60 °C or <4 °C
Brucella abortus	Contact infection (handling infected animals/materials). Also via raw milk	Herd health management (vaccination, serological screening)	Milk pasteurization* Hygiene precautions for at-risk workers
Cronobacter spp.	Associated with powdered infant formula		Good manufacturing and hygiene controls in the production environment and during rehydration/reconstitution of the product. Control storage temperature and time of reconstituted product
Shiga toxin-producing *Escherichia coli* (STEC) also known as verotoxin-producing *E. coli* (VTEC)	Mainly via raw milk	Hygienic husbandry and management of animal wastes and effluents from dairy farms	Milk pasteurization.* Good manufacturing and hygiene practices
Campylobacter jejuni	Mainly via raw milk	Hygienic husbandry and management of animal wastes and effluents from dairy farms	Milk pasteurization.* Good manufacturing and hygiene practices
Listeria monocytogenes	Mainly via raw milk and soft cheeses. Also contact infection from handling infected animals/materials	Hygienic husbandry, herd health management	Milk pasteurization.* Good manufacturing and hygiene practices. Prevention of post-processing contamination
Mycobacterium bovis	Mainly via raw milk	Hygienic husbandry, herd health management, tuberculin testing and slaughter of positive reactors	Milk pasteurization*
Salmonella spp.	Mainly via raw milk	Hygienic husbandry and management of animal wastes and effluents from dairy farms	Milk pasteurization.* Good manufacturing and hygiene practices
Staphylococcus aureus	Mainly via raw milk	Milking hygiene, mastitis control	Milk pasteurization.* Good manufacturing and hygiene practices. Process and storage control
Streptococcus zooepidermicus *S. agalactiae*	Mainly via raw milk	Milking hygiene	Milk pasteurization*
Yersinia enterocolitica	Mainly via raw milk	Impractical (wide range of animal hosts)	Milk pasteurization*
Coxiella burnetii	Via aerosol and milk. Also possibly tick bites	Tick control, herd health management	Milk pasteurization.* Hygiene precautions for at-risk workers

* Thermal pasteurization or processes determined to be equivalent to thermal processing.
Source: adapted from EFSA, 2009.

BOX 6.1
***Mycobacterium bovis* and tuberculosis**

In developed countries, bovine tuberculosis (bTB) has been almost eradicated after the implementation of control measures such as testing, culling of cattle and pasteurization of milk. Properly controlled heat treatment of milk, e.g. pasteurization, inactivates *M. bovis* and has had a major impact on reducing transmission. However, bTB is re-emerging in some developed countries and there is a limited threat to public health where unpasteurized raw milks and cheeses are consumed. In many developing countries controls and surveillance systems are often inadequate or unavailable, bTB is still highly prevalent in cattle, pasteurization is not widely practiced or is replaced by boiling unpasteurized milk prior to consumption and milk hygiene and environmental controls are insufficient; in such countries it is estimated that 10–15 percent of human TB cases are caused by bTB (Ashford *et al.*, 2001). Leite *et al.* (2003) report that *M. bovis* accounts for about 5 percent of human tuberculosis cases in Brazil. Most human tuberculosis cases caused by *M. bovis* occur in young people and result from drinking or handling contaminated milk (Thoen, Lobue and de Kantor, 2006). Furthermore, the HIV/AIDS pandemic poses an additional serious public-health threat due to increasing incidence of tuberculosis/HIV/AIDS co-infection, especially where bTB is prevalent in domestic and wild animals (Cosivi *et al.*, 1998).

The proportion of tuberculosis cases in humans caused by bTB depends on the prevalence of the disease in cattle, socio-economic conditions, consumer habits, food hygiene practices and medical prophylaxis measures (Shitaye, Tsegaye and Pavlik, 2007). Reducing the prevalence of bTB in cattle in Ethiopia, for example, would require improved knowledge on actual prevalence of the disease, addressing the prevailing technical and financial limitations, provision of veterinary infrastructure and overcoming cultural and/or traditional beliefs and geographical barriers (Shitaye, Tsegaye and Pavlik, 2007). High prevalence of bTB in endemic areas is expected to restrict sale and movement of livestock because of sanitary requirements of importing countries.

present in raw milk and soft cheeses (Swaminathan and Gerner-Smidt, 2007), is of significant public health concern as infection in pregnant women may result in spontaneous abortions or stillbirth. An important factor in food-borne listeriosis is that the pathogen can multiply at refrigeration temperatures when given sufficient time (FAO and WHO, 2004a).

Outbreaks of pathogenic *E. coli*, including STEC and enteraggregative *E. coli* (EAEC), have been attributed to a variety of dairy products, most often those involving unpasteurized or inadequately pasteurized milk or raw milk products (Fegan and Desmarchelier, 2010). STEC are carried by healthy adult dairy cattle and have been detected in raw milk on farms although the enterohaemorrhagic *E. coli* strains of STEC such as serotype 0157 have a much lower occurrence.

Cronobacter spp. have been linked with serious infections in infants (FAO and WHO, 2004b, 2006a; Mullane *et al.*, 2007), notably following the consumption of

powdered infant formula. They have been implicated in outbreaks of meningitis and enteritis, especially in infants. While illness can occur in all age groups, infants less than 12 months old are described as vulnerable and infants less than two months old as most vulnerable (FAO and WHO, 2006a). The source of *Cronobacter* spp. is not fully understood; however, they have been isolated from milk-processing plants.

Finally, an unclear picture is emerging regarding *Mycobacterium avium paratuberculosis* (MAP), which is giving rise for concern due to possible linkages with Crohn's disease (Greenstein, 2003). Viable MAP is found in cow's milk, it is ubiquitous in the environment and it is not reliably killed by standard pasteurization.

Measures to prevent the spread of zoonotic diseases among animals and from animals to milk include controlling infection from feed and fodder, improving shelter and hygiene of animals and the environment, safe waste management and good management of veterinary drug application.

6.2.2 Chemical hazards

Chemical hazards include contaminants (heavy metals, radionuclides, persistent priority pollutants, e.g. polychlorinated biphenyls [PCBs] or dioxins, and mycotoxins) and residues of other chemicals that are used or added during the animal production or manufacturing processes, such as veterinary drugs, pesticides, substances migrating from packaging materials (e.g. isopropyl thioxanthone [ITX] and bisphenol A [BPA]). The source of chemical hazards varies and may include air, soil, water, substances used in animal husbandry practices and animal feedstuffs.

In addition, some contaminants may enter the dairy chain during dairy processing and packaging or through deliberate adulteration (e.g. melamine). Special attention should be given to chemical food-safety hazards as once they are present in concentrations greater than the acceptable daily intake (ADI) or acute reference dose it may be difficult to reduce them to an acceptable level during processing. It should be noted, however, that residues deplete in milk over time and withholding times following treatment are used to permit depletion of residues of veterinary medicines and pesticides. Pasteurization and other forms of heat treatment have limited or variable effects on chemical contaminants.

At farm level the application of good agricultural and veterinary practices are key. Achieving the balance between prudent use of veterinary drugs to control zoonoses and animal health diseases and ensuring the safety of foods of animal origin is essential. However, it is very important to realize that the detection of residues alone does not necessarily mean there is a risk to human health – safety levels are established for different potential contaminants through assessment of their toxicity, establishment of health-based guidance values and relating these to the estimate of dietary exposure (WHO, 2009).

Problems may still exist where highly or moderately persistent pesticides are used in malaria control programmes and against livestock endo- and ectoparasites and agricultural pests. This may result in contamination of air, water and soil with residues and their subsequent transfer to milk-producing animals such as cows and buffaloes if they feed on contaminated grass or hay, drink contaminated water or inhale them as aerosols. Being highly lipophilic, organochlorine pesticides accumulate in the fat of animals and are excreted through milk. Several health effects of such pesticides have been reported, ranging from systemic effects on cardiovascular and

respiratory function to genotoxic effects (Bhandare and Waskar, 2010). It is therefore imperative that the level of pesticide residues is kept well below recommended tolerance levels to minimize the risk to human health.

The main chemical hazards found in milk and dairy products and related control measures are listed in Table 6.3.

Veterinary drugs (Antimicrobials)

Veterinary drugs include various classes of therapeutic medicines used to treat a variety of diseases occurring in food-producing animals, including the control of endoparasites and ectoparasites. Antimicrobials are the most important for milk due to the high degree of local treatment, i.e. intermammary infusion. The most commonly used antimicrobial drugs are antibiotics used to control mastitis and rickettsial diseases in dairy cattle.

While antimicrobials are most commonly used to treat cattle for mastitis in temperate countries, in tropical countries they may also be used to treat endemic diseases and may even be added to milk as a preservative because of lack of refrigeration (Kurwijila *et al.*, 2006).

TABLE 6.3
Main chemical hazards found in milk and dairy products and related control measures

Chemical hazard	Main means of on farm control – preventive controls	Main means of control in processing and food handling – secondary controls
Antibiotics	Good animal husbandry and good veterinary practices (GVPs). Adherence to recommended MRLs and withholding periods	Testing at milk collection point
Pesticides and Insecticides	Use of authorized products. Safe application and observance of withdrawal times	Compliance with regulatory controls and periodic testing at milk collection point
Growth promoters	Authorized use and GVPs	Testing at milk collection point
Dairy plant cleaning chemicals	Use of authorized products, good plant equipment design, good hygiene practices	In-plant controls and relevant testing
Mycotoxins, e.g. aflatoxin	Feed hygiene and control and screening tests on animal feeds	Testing of milk and dairy products for M1 aflatoxin metabolite
Dioxins	Environmental controls	Testing of milk and dairy products
PCBs	Environmental controls	Testing of milk and dairy products
Food additives	Use of registered substances, good manufacturing practices (GMP)	Testing of milk and dairy products
Processing aids	Use of registered substances, GMP	Testing of milk and dairy products
Radionuclides	Detection and discarding of contaminated milk	Testing of milk and dairy products
Melamine	GMP, sourcing feed from reliable supplier	Sourcing from reliable supplier Testing of milk and dairy products

Note: Testing of milk and dairy products is not as effective as the recommended preventive controls in ensuring that milk and milk products do not contain significant chemical hazards. If final products contain excessive levels of chemical hazards they must be removed from the market.

Maximum permissible limits for antibiotic residues in foods are established to ensure prudent use of antimicrobials and safeguard public health. Excessive residues of antimicrobials in milk can also affect processing because they may partially or completely inhibit acid production by starter cultures in cheese- and yoghurt-making, or inadequate ripening and ageing of cheese and resultant flavour/texture defects.

Residues in milk can be minimized by adhering to good veterinary and husbandry practices. FAO and WHO (2009) sets out the overarching principles and guidance for governments on the design and implementation of national and trade-related food-safety-assurance programmes for residues of veterinary drugs and provides guidelines on best use of veterinary drugs by food producers and processors.

In practice, at the national level each registered antimicrobial preparation has a recommended withdrawal time before milking which must be adhered to in order to avoid excessive levels of residues in the milk (Fischer *et al.*, 2003). Failure to adhere to withholding periods is the most commonly cited reason for drug residues in marketed milk in temperate countries (Zwald *et al.,* 2004). Other important reasons why residues occur at excessive levels include incorrect route of administration and dosage, use of antimicrobials not registered for dairy cows and incorrect use without taking into consideration lactation status.

Antimicrobial resistance

Antimicrobial drugs play a critical role in disease prevention, thus contributing to animal and human health. However, the misuse or inappropriate use of antimicrobials for treatment and prevention of diseases in food animals may lead to the emergence and spread of micro-organisms resistant to antimicrobials, leading to reduced effectiveness of antimicrobials in treating diseases in humans and animals. The risk appears to be greater in countries that have weak, inadequate or non-existent national policies, regulatory, surveillance and monitoring systems for antimicrobial resistance and antimicrobial drug usage. To address this issue at the global level, the Codex Alimentarius Commission has adopted guidelines for risk analysis of foodborne antimicrobial resistance (FAO and WHO, 2011a) and a code of practice to minimize and contain antimicrobial resistance (FAO and WHO, 2005).

Antimicrobial resistance is not a great concern where milk is routinely pasteurized or receives equivalent processing, because these inactivate bacteria. However, it may be of concern where:

- pasteurization is not mandatory or is mandatory for cow milk but not for milk from other species, e.g. sheep, goat or camel;
- post-pasteurization or processing contamination occurs (this is not common but does happen);
- dairy products are made from unpasteurized milk or cream, particularly soft cheeses where processing does not inactive bacteria sufficiently; or
- consumers prefer unpasteurized products.

Growth promoters

The growth promoter of most relevance to milk and dairy products is recombinant bovine somatotropin (rBST), a hormone used in some countries to increase milk production in lactating bovine cows (Khaniki, 2007). FAO and WHO (1998)

concluded that rBST can be used without any appreciable health risk to consumers; this reaffirmed the ADI and maximum residue limits (MRLs), which had previously been set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) as "not specified"[53] based on the assumption that the drugs are administered to food-producing animals in accordance with good practice in the use of veterinary drugs.

Until now, no international Codex Alimentarius standard has been adopted for rBST, although further scientific evaluation has been requested from JECFA (the responsible FAO/WHO Committee). In the absence of a global standard, control and use of rBST differs between countries; some allow its use in dairy cattle while others have banned its use because of concern over animal welfare and public health.

Because it is not possible to differentiate between the hormones produced naturally by the animal and those used to treat the animal, it is difficult to determine exactly how much of the hormone used for treatment remains in the meat or the milk. Studies indicate that if correct treatment and slaughter procedures are followed, the levels of these hormones may be slightly higher in meat or milk from treated animals than in those from untreated animals but are still within the normal range of natural variation known to occur in untreated animals.

Pesticides and insecticides

Pesticide residues in milk may come from a number of sources, including water, soil or air, contaminated animal feeds or pesticides applied to cattle or their direct living environment to kill disease vectors (mites, ticks, insects) (Fischer *et al.,* 2003).

Significant advances have been made in strengthening regulatory and registration controls, quality and safety of pesticides and application of best practices by farmers and processors. Newer pesticides are more readily metabolized and excreted than were earlier pesticides, and thus do not tend to accumulate within the animal's body. The Codex Alimentarius Pesticide residues in food and feed database lists MRLs for a wide range of pesticides (FAO and WHO, 2012). The application of modern pesticides on feed and forage plants presents little risk of significant residues appearing in milk as long as farmers adhere strictly to good agricultural practice.

Dairy-plant chemicals

Cleaning and disinfection of dairy plants commonly involve the use of cleaning compounds and sanitizers, many of which may be extremely toxic at high levels. They should thus be stored and used according to manufacturers' directions and in ways that ensure that they do not contaminate milk or dairy products and equipment used to process and handle dairy products (Fischer *et al.*, 2003). Thorough draining and rinsing after use are essential and common good hygiene practice.

[53] **ADI "not specified" – veterinary drugs**
Available data on the toxicity and intake of the veterinary drug indicate a large margin of safety for consumption of residues in food when the drug is used according to good practice in the use of veterinary drugs. For that reason, and for the reasons stated in the individual evaluation, the Committee has concluded that use of the veterinary drug does not represent a dietary hazard to human health and that there is no need to specify a numerical ADI (WHO, ILO and UNEP, undated).

Mycotoxins

Aflatoxins, which are produced by *Aspergillus flavus* and *Aspergillus parasiticus*, may be present in animal feed. Where cattle consume feed contaminated with aflatoxin B_1, aflatoxin M_1 is the main aflatoxin in milk or dairy products due to a conversion from aflatoxin B_1. Aflatoxin M_1 is a genotoxic carcinogen which poses a significant risk to human health even at low concentrations (IARC, 1993). The risks from aflatoxin exposure from milk need careful consideration, particularly in infants and young children. The Codex Alimentarius Commission has set the maximum limit for aflatoxin M_1 in milk at 0.5 µg/kg (FAO and WHO, 1995a).

Aflatoxin contamination of milk can be prevented by preventing fungal growth in feed.

Food additives, flavours and processing aids

Chemicals added to foods include food additives (such as stabilizers, acidifiers, emulsifiers, colours, thickeners and preservatives), flavouring substances and processing aids. These chemicals impart a flavour, protect food from microbiological deterioration, enhance functional characteristics or improve shelf-life and appearance. Levels at which these chemicals are likely to become harmful to human health are generally many times greater than they would occur under normal usage (Fischer *et al.,* 2003). However, where weak controls and practices do exist, the prescribed usage levels may be exceeded, resulting in a harmful or even toxic effect. ADIs for a range of food additives are given in the Codex Alimentarius General Standard for Food Additives (FAO and WHO, 1995b).

Chemicals formed during processing or final use

Some substances can be formed or enter the milk products during processing. Examples include the following:

- **Advanced glycation end products (AGEs)** are formed during heat processing of foods containing protein and carbohydrate. Infant formulas are heated during the manufacturing process to ensure their microbiological safety and therefore AGEs may be formed. AGEs may play an important adverse role in atherosclerosis, diabetes, aging and chronic renal failure (Krajcovicová-Kudlácková *et al.,* 2002).
- Contamination with **ITX**, normally contained in the ink used to print on packaging materials, has been reported in some baby milk and other dairy products (Benetti *et al.,* 2008).
- **BPA** is used to make polycarbonate plastics and epoxy resins. Polycarbonate is widely used in food contact materials, such as infant feeding bottles and food containers while epoxy resins are used as protective linings for canned foods, glass jars including containers used for infant formula. These uses result in consumer exposure to BPA through the diet. There are concerns about possible adverse human health effects especially on reproduction, the nervous system and behavioural development in consequence and due to the relatively high exposure of very young children compared with adults. An FAO/WHO expert meeting convened in 2010 examined the available data on this issue, and identified a number of gaps in knowledge and provided a range of recommendations for the generation of further information and the design

of new studies to better understand the risk to human health posed by BPA (FAO and WHO, 2011b).

- **3-MCPD** is a contaminant which occurs through food processing and has been detected in a number of foods including infant formula and follow-up formula. Studies to date show that there is a need for action to reduce the levels but there is no acute risk (BfR, 2007). To investigate any potential risks based on current data, 3-MCPD is on the priority list proposed for evaluation by JECFA to undertake a toxicological and exposure assessment.

Environmental contaminants: toxic elements and compounds

Milk and dairy products can be a source of heavy metals, e.g. lead, cadmium and nickel. These can originate in the environment, animal feeds, water used in dairy farms and dairy plants and sewage sludge used as a soil amendment. It is well established that lead and cadmium are toxic to humans, and children may have an increased exposure to these metals compared with adults because of their lower body weight (Khaniki, 2007).

Foods high in animal fat, such as milk, meat, fish and eggs, are the main source of dioxins and PCBs in the human diet. These chemical enter the food chain from the environment, industrial sources and feeds. These persistent organic pollutants tend to accumulate in lipid tissues; hence, in lactating animals dioxins and dioxin-like PCBs are excreted partly with milk fat. Key ways to reduce PCB and dioxin in dairy products is to ensure feed is produced in areas that are not contaminated with these chemicals and to avoid contaminated feeds (FAO and WHO, 2006b). Short-term exposure of humans to high levels of dioxins may result in skin lesions, such as chloracne, patchy darkening of the skin and altered liver function. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. Dioxin is classified as "known human carcinogen" (IARC, 1993). However, dioxin does not affect genetic material and there is a level of exposure below which cancer risk would be negligible (WHO, 2010).

Radionuclides are a rare contaminant in milk, but are of concern when radioactive contamination results from a nuclear or radiological emergency. Experience from the Chernobyl accident and more recently the release from the Fukushima Daiichi plant have shown that immediately following an accident milk is susceptible to contamination with high levels of iodine-131. However, likely health impacts can be minimized immediately by administering potassium iodide tablets to the affected population.

Intentionally added contaminants

The intentional contamination of food refers to the deliberate action of adding a harmful or deleterious substance to food primarily for the purposes of economic gain. It deceives the consumer and direct health consequences may also result.

The adulteration of milk with water, starch, gelatine, carbonates/bi-carbonates, urea etc. for economic gain is reported to be a prevalent practice in India (Bhandare and Waskar, 2010). Some of these adulterants can harm human health. For example, adding water to milk can have adverse health effects or consequent risks in many developing countries (Grace, Baker and Randolph, 2009).

BOX 6.2
Melamine contamination of milk in China

Melamine is mainly used in the synthesis of melamine formaldehyde resins, which in turn are used in the manufacture of laminates, plastics, coatings, glues and some dishes and kitchenware. When added to food it boosts the apparent protein content because commonly used methods for protein analysis do not distinguish between nitrogen from protein and non-protein sources (Gossner *et al.*, 2009). Nitrogen content is often used to estimate protein levels in milk and hence is an agreed indicator of the quality of milk and assurance that it has not been watered down to increase the volume. In 2008, the Chinese government announced a recall of infant milk powder that was contaminated with melamine (BBC News, 2010). A wide range of milk and milk-containing products, including liquid milk, ice cream and yoghurt, was found to be contaminated (Xiu and Klein, 2010).

The impact of the contamination was amplified because contaminated milk products were exported from China to many countries, leading to a public health concerns in importing countries. In addition to the serious impact on health, other consequences included financial loss to the dairy sector, a large recall of food products at international level, pressure on importing countries to control imports, disposal and dumping of large quantities of contaminated milk and need for consumers to identify alternative sources of safe milk for their families. To address this issue, immediate actions were taken by the government and industry to improve the safety of dairy products. However, despite this, sporadic reports of melamine in milk continue. In February 2010 news media reported that a number of old batches of contaminated milk powder that were not destroyed as ordered by the Chinese authorities may still have been available for sale (Le and Hornby, 2010).

In parallel, many countries set interim tolerance levels for melamine in foods and milk and milk products which will be re-examined as new data become available. At the global level, the Codex Alimentarius Commission adopted global standards for melamine: maximum levels of 2.5 mg/kg in food, 2.5 mg/kg in feed and 1 mg/kg in powdered infant formula (2010), and a maximum level of 0.15 mg/kg in liquid infant formula (2012) (FAO and WHO, 1995a).

More recently, melamine was added to milk in China to boost its apparent protein content (the basis on which the price for milk was set). More than 294 000 infants became ill after consuming the contaminated milk, more than 50 000 infants were hospitalized and six deaths were confirmed (WHO, 2008a). An increased incidence of kidney stones and renal failure was observed in infants and babies.

6.2.3 Physical hazards

Physical hazards include a variety of materials often referred to as extraneous materials or foreign objects (Table 6.4). A physical hazard may be defined as any physical material not normally found in a food which may cause illness or injury to the individuals using the product. The potential health costs of a physical hazard are

TABLE 6.4
Physical hazards origin and control measures

Hazard material	Origin/source	Control measures
Glass fragments	Bottle, jars, light fixtures, utensils	Examination of incoming materials
Wood splinters	Fields, pallets, boxes	Effective pest control measures
Metal fragments, screws & rivets	Machinery, wire, staples, pins	Maintenance of hygienic environment
Machine filings		Control of small loose items such as screws, drawing pins etc.
Insects or insect fragments	Fields, plant, pest-control process	Maintenance procedures designed to avoid contamination
Insulation/paint	Building, storage area	Protected light fittings in all food-handling areas
Dirt, dust or hair	Unclean storage, environment, storm	Training in good personal hygiene practices
Plastic material fragments	Ingredient bags, aprons, gloves, equipment, fittings	Maintenance/replacement of filters/ sifters
Personal effects (jewellery, buttons, nail fragments, nail varnish, dressings)	Incorrect storage, pockets	Provision of on-line metal detectors and x-ray detector
		Decanting from packaging materials away from food-handling areas
		No jewellery policy
		No smoking policy
		No glass policy

likely to be greater if the company is producing a sensitive product, such as infant formula and infant foods that contain milk. These manufacturers have some of the best programmes in the world for ensuring that foods produced are free of foreign material, especially glass, and are scrupulously clean and processed to exacting standards of safety.

6.3 HEALTH IMPACT OF OUTBREAKS OF FOOD-BORNE ILLNESS ATTRIBUTED TO MILK AND DAIRY PRODUCTS

While there is evidence that milk can contain pathogens and chemical substances that may cause illness, with many documented outbreaks implicating milk and dairy products, there is very little information on the actual health burden and costs attributable to unsafe milk and dairy products.

Fewer data and statistics are available from developing countries than from developed countries. This lack of data limits our ability to identify which food pathogens or chemical substances present the greatest risk to consumer health; actual risk will vary depending on production and processing environments and controls. National and international efforts are ongoing to improve data collection through enhanced surveillance and reporting systems, more effective investigation of outbreaks implicating milk and milk products and enhanced information exchange on the safety of milk and milk products traded at national, regional and global levels.

A recent study in the United States listed *Listeria* in dairy products as the fifth most costly pathogen–food combination in terms of cost of illness and loss of quality-adjusted life years, after *Campylobacter* in poultry, *Toxoplasma* in pork,

Listeria in deli meats and *Salmonella* in poultry (Batz, Hoffman and Glenn Morris Jr., 2011). In the United Kingdom, where milk is commonly pasteurized, it is estimated that less than two percent of all food-borne diseases are attributable to milk (Casemore, 2004).

Examples of outbreaks of food-borne illnesses involving milk and dairy products are presented in Table 6.5.

6.4 ASSESSING RISK AND PRIORITIZATION OF FOOD-SAFETY RISKS ASSOCIATED WITH MILK AND DAIRY PRODUCTS

All foods have the potential to cause food-borne illness, and an assessment of risk and understanding the likelihood of hazards being present is the basis for determining effective prevention and control measures to achieve the appropriate level of protection. Evaluating which hazards are most likely to be present in milk/dairy products requires knowledge and data specific to the product and place of production. For instance, microbiological or chemical hazards that are not relevant or present in the geographical area of concern can be ruled out at an early stage. Where it can be verified that certain control measures are successfully applied to prevent or significantly reduce introduction of a pathogen or chemical into the herd, including efficient eradication programmes, the pathogen/chemical in question can be ruled out. In contrast, any hazards that can be introduced into the milk product during and after processing (from the environment or human contamination) should be considered. An understanding of the intended use of the product and the final consumer is also an essential aspect of managing risk. For example, when assessing milk as a source of contaminants and pathogens, etc., particular attention should be paid to infants and children as they may have increased risk of exposure as they consume larger quantities of milk and dairy products relative to their body weight than adults, and their dietary patterns are often less varied.

Where available, data and documentation on the effectiveness of national programmes, the effectiveness of individual producer screening programmes and epidemiological and other historical data that have been associated with the type of product will greatly assist in assessing the prioritization of food-safety risks associated with milk and dairy products.

Consumer behaviour and preferences can also have a bearing on risk. In some countries, consumers prefer to buy raw milk and boil it themselves rather than pay more for pasteurized, packaged milk, while other consumers in the same areas will choose to consume raw milk, because they believe that this milk is more pure, natural and healthy than industrialized milk (e.g. pasteurized, ultra high temperature [UHT]). In Kenya, high-income consumers express the same preference for raw milk as those with lower income. As a result, the market for raw milk and traditional products can dominate the dairy sector in developing countries – over 90 percent of the dairy market in Tanzania and Uganda, 83 percent in India and 85 percent in Kenya is through informal channels (Omore *et al.*, 2001). There is also a trend among some consumers in developed countries to consume unpasteurized milk in the belief that is healthier (Hegarty *et al*., 2002). Different products may present different food-safety hazards and it is important to consider the intrinsic risks associated with milk and individual dairy products as well as other extrinsic risk factors (industry practices, supply chain and consumer preferences) as part of risk assessment.

TABLE 6.5
Examples of outbreaks of food-borne illnesses attributed to milk and dairy products

Cause	Food category	Country	Timeline	Outbreaks	Cases
Salmonella spp.	Dairy products	Australia	1995–2008	7	226
	Raw milk	US	2000–2006	1	107
	Pasteurized milk	US	2000–2006	3	254
	Cheese made with raw milk	US	2000–2006	3	138
Campylobacter	Dairy products	Australia	1995–2008	6	85
	Raw milk	US	2000–2006	33	497
	Pasteurized milk	US	2000–2006	1	200
	Cheese made with raw milk	US	2000–2006	3	85
Norovirus	Dairy products	Australia	1995–2008	3	123
C. perfringens	Dairy products	Australia	1995–2008	1	27
Cryptosporidium	Dairy products	Australia	1995–2008	1	8
S. aureus	Dairy products	Australia	1995–2008	1	2
	Powdered skimmed milk used for low-fat milk and yoghurt	Japan	2000	1	13 809
	Cheese	Brazil	1994	1	7
	Stilton cheese made with unpasteurized milk	England	1988	1	155
	Cheese made with raw milk	Israel		1	3
Listeria	Cheese made with raw milk	US	2000–2006	3	36
	Cheese made with pasteurized milk	US	2000–2006	1	3
	Quargel (sour-milk curd cheese)	Austria, Czech Republic, Germany	2009–2010	1	34
E. coli	Raw milk	US	2000–2006	6	35
	Cheese made with raw milk	US	2000–2006	1	3
	Gouda cheese made with unpasteurized milk	Canada	2002	1	13
	Fresh goats cheese made with unpasteurized milk	France	2004	1	3
	Pecorino cheese made with unpasteurized milk	Italy	2006	2 (10 days apart)	47
	Ice cream	Belgium	2007	1	5

TABLE 6.5 *(continued)*

Cause	Food category	Country	Timeline	Outbreaks	Cases
Chemical contamination	Dairy products	Australia	1995–2008	1	23
Melamine	Contaminated powdered infant formula	China	2008	1	>54 000
Unknown	Dairy products	Australia	1995–2008	6	86

Source: Fegan and Desmarchelier, 2010; Oliver *et al.*, 2009; EC, 2003; NSW Food Authority, 2009; WHO, 2000; WHO, 2008b; Fretz *et al.*, 2010.

The composition of many milk products makes them a good media for microbial growth, and various processes have been developed over the centuries in part to extend the shelf-life of dairy products and provide a more diverse range of foods. However, these may themselves give rise to specific hazards.

The following examples illustrate the linkage between milk product and potential food hazard:

- Pathogen loads may be low in well-made hard cheeses because of their relatively low pH, relatively high salt content, curd heating, long maturation and possible presence of bacterocins (Fox and Cogan, 2004).
- High-moisture, fast-ripening cheeses are more likely to harbour pathogens than are low-moisture, slow-ripening varieties. Outbreaks of listeriosis have been associated with soft cheeses.
- Powdered infant formula may contain *Cronobacter* spp. (an opportunistic pathogen emerging as a public-health concern), which affects infants in particular, with neonates (up to 28 days old) and infants under two months of age at greatest risk (FAO and WHO, 2006a). Additionally, the reconstitution of powdered infant formula under unhygienic conditions or with contaminated water and prolonged storage at warm temperatures can lead to an unsafe product.
- *S. aureus*, a pathogen found in milk in bulk tanks, can produce a heat stable enterotoxin that causes food poisoning. A large-scale outbreak occurred during June 2000 in Japan caused by consumption of low-fat milk produced from skimmed-milk powder contaminated with *S. aureus* enterotoxin A (Asao *et al.*, 2003). Ice-cream mix can also provide the right conditions for the growth of *S. aureus*.
- Non-pasteurized milk and inadequately pasteurized milk contaminated with *Campylobacter jejuni* is a common source of this food-borne pathogen (Fahey *et al.*, 1995; Evans *et al.*, 1996).

Increasing attention is focusing on the risks associated with the consumption of raw milk and raw-milk cheeses; given that these products are not pasteurized or subjected to processes equivalent to thermal pasteurization, alternative safety controls are required. For example, high-moisture raw-milk cheeses are of considerable concern although most of these have a low initial pH (4.6) and appear to be safe (Fox and Cogan, 2004).

BOX 6.3
Raw milk and raw milk cheeses

Important safety controls for raw-milk cheeses include minimizing the number of pathogens in the milk through hygienic production and milking conditions; removing any remaining bacteria through technologies such as bactofugation or microfiltration, or prevent them from growing through low pH; using long maturation time and high salt content to lower the water activity; controlling the temperature at which the cheeses are processed and stored; and selecting starter cultures that produce bacteriocin.

Despite these controls, raw milk and raw-milk cheeses have been implicated in a number of outbreaks of food-borne diseases, and there is a need for concerted action by government and producers to ensure that controls specific to the particular product are implemented correctly and thoroughly.

Problems can arise when raw milk is used in cheese types in which hazards are not easily controlled during processing and with pathogens such as *Mycobacterium bovis,* which can survive in mature, unpasteurized cheeses, is very resistant to chemical disinfectants and is largely unaffected by the pH of the cheese (de la Rua-Domenech, 2006). Traditional cheese varieties made from raw milk should only be made from milk from herds that are certified as free of brucellosis and bTB (Creamer *et al.*, 2002).

Public-health authorities in many countries require that cheese made from raw milk be aged for 60 days, although this practice may not be fully effective. An alternative, risk-based approach is to require demonstration that the cheese processing can consistently provide a level of health risk equivalent to or lower than that produced by thermal pasteurization. Labelling and consumer education may also be required to support informed consumer choice.

Risks and effectiveness of associated control measures also need to be assessed in the context of the actual production environment and market chain, which differ markedly between countries and especially between developed and developing countries.

In developed countries, the milk supply chain is usually quite sophisticated, organized and large scale, and use of technologies to mitigate risks, especially refrigeration and pasteurization, is common. The milk supplied to modern cheese factories and dairy plants is of very high quality and after pasteurization contains only a few hundred bacteria per ml of milk (Fox and Cogan, 2004).

In contrast, in many developing countries the market is dominated by unpasteurized, informally marketed milk produced by smallholders (De Leeuw *et al.*, 1999; COMESA and EAC, 2004). In general, developing countries still face very specific challenges in maintaining the quality of the milk from milk producer to dairy plant for processing or to the market for direct sale.

A number of challenges prevail in the more informal dairy sector in rural areas, such as poor infrastructure and transport systems, lack of or interrupted electricity supply, poor hygienic conditions and inadequate transport and storage. Many

producers have to walk to markets; hence, milk may be stored at high temperatures for several hours and may be further contaminated from human or environmental sources. In these circumstances the risk of spoilage and of increased pathogen loads is high. This can be further compounded where the weather is warm and infrastructure and refrigeration facilities at retail outlets are limited. It is imperative that practical methods are applied to preserve and protect the milk during transport and storage.

The challenge facing policy makers is to balance the objectives of consumer protection, safe food and livelihood security. This requires evidence-based methods that assess the risks posed by dairy products originating in the informal sector and determining how to manage these risks in ways that consider both health and economic protection of the poorer farmers and traders who constitute the majority of the dairy sector (Grace *et al.,* 2006). Regulations, management strategies and control measures need to be appropriate with the end objective of ensuring the safety of the product and consumer health protection. This includes consideration of cost effectiveness. This is discussed further in the following section.

6.5 CONTROL AND PREVENTION: IMPLEMENTING SAFE FOOD PRACTICES

The ability of a country to prevent and address outbreaks of food-borne diseases is influenced by the maturity and capacity of the national food control system, the prevailing conditions within the farming and food-processing sectors, and the practices and capacities of food-chain operators. Responsible authorities must have a policy and legislative framework for food safety and quality, adequate infrastructure and properly trained inspectors and personnel in place if they are to function effectively. This should provide a coordinated and a preventive approach to food-safety management along milk and dairy-product chains. Food-safety decisions and policies should be based on an understanding of the priority risks associated with milk and dairy products in the national milk and dairy sector. Working with dairy farmers and milk and dairy processors is essential to identify appropriate control measures and ensure their application at the most effective part of the chain. Different countries, different dairy products and different production environments give rise to a range of diverse situations. Examples of the diversity of the type of contexts food-safety policy-makers may need to address include the following:

- a rapid and significant increase in a country's dairy production (e.g. China, where production increased from 10 million tonnes in 2001 to an estimated 39 million tonnes in 2009) can place additional needs on quality and safety control systems (USDA, 2008);
- the existence of an informal market, common and important in many developing countries, characterized by small-scale production, large number of producers, lack of cold-chain market pathways, in which raw milk is sold to the consumer who then boils it, and which is subject to little or no regulatory control (Omore *et al.,* 2001);
- addressing the risk of antimicrobial residues in milk, which may require attention to milk-production practices employed by farmers and use of antimicrobials, programmes for testing of residues at milk collection centres and associated action.

A range of government controls can be applied to prohibit a certain practice or use of a substance or regulations can be put in place that set maximum levels for specific substances (e.g. dioxins, aflatoxin M_1), MRLs for residues of pesticides and veterinary drugs or establish microbiological criteria for microbial pathogens. Guidance and rules for good hygiene practice and the application of the Hazard Analysis Critical Control Point (HACCP) system where appropriate throughout the chain are important control measures.

Achieving a safe final product from raw milk to the point of consumption will require a combination of control measures that together should achieve the appropriate level of health protection. Preventive and control measures will not necessarily be the same in all countries or production environments – they need to be appropriate to the level of assessed risk, local production and processing procedures and the differing characteristics of milk from various milking animals. For example, many countries rely on controls other than an organized heat-treatment step such as pasteurization: in East Africa, for example, milk produced by the smallholder sector and sold through informal channels is generally boiled by the consumer before drinking. This is effective for killing most pathogens; however, if the consumer is unaware of the potential dangers of unpasteurized milk or forgets or chooses not to boil the milk they may face higher risk of food-borne illnesses. Other control measures can also be put in place, including a shorter chain from producer to final consumer or the practice of the consumer purchasing smaller quantities as and when needed (Grace *et al.,* 2008). Farm practices should ensure that milk is produced by healthy animals under acceptable conditions for the animals and in balance with the local environment. It is important that control measures are applied during both primary production and processing to minimize or prevent the microbiological, chemical or physical contamination of milk.

A general distinction can be drawn between the types of control measures used for microbiological hazards and those used for chemical and physical hazards. In addressing microbiological hazards it is essential to prevent unhygienic practices and conditions in the production, processing and handling of milk and milk products. Minimizing the initial microbial load in milk and prevention of the growth of micro-organisms are key to ensuring the safety of milk and dairy products. The initial microbial load significantly impacts the performance (e.g. reduction in amount or number) required of the microbiological control measures applied during and after processing. Some issues that may influence the microbiological load include herd size, distance from collection centre to dairy, temperature of the milk when it reaches the dairy plant or market, presence or absence of a cold chain, and duration of transportation.

Although pasteurization may reduce numbers of micro-organisms in milk, it is not a substitute for good hygiene practices, especially as milk may be consumed raw. On occasion pasteurization may not destroy all pathogens in the milk, especially if it is not done properly (i.e. required time and temperature not followed). To be effective, pasteurization does require a cold chain from the time the product is pasteurized until it is consumed. As this can be challenging in many countries, alternative methods such as the lactoperoxidase (LP) system may be used (Box 6.4).

Furthermore, where pathogens enter dairy plants in contaminated raw milk the pathogens can persist in the plant in biofilms and contaminate subsequent batches of

BOX 6.4
Lactoperoxidase system

Thermal pasteurization and cool storage are the main methods for safeguarding the quality of milk in developed countries. However these methods are not always possible in all countries and alternative methods are needed that are safe, cheap and easily applicable under farm conditions. One such system is the LP system. The LP system exploits antimicrobial compounds naturally present in milk by increasing the concentrations of two components or activators (thiocyanate and hydrogen peroxide) reacting with each other. This reaction is catalysed by the enzyme LP, which is naturally present in milk, and leads to the formation of antibacterial compounds. The activation of the LP system effectively extends the shelf-life of raw milk by 7-8 hours under ambient temperatures of around 30 °C or longer at lower temperatures. The effectiveness depends on the initial amount and type of microbiological contamination and the temperature during the treatment period. The use of the LP system for preservation of raw milk has been reported in several countries (Björck, Claesson and Schulthess, 1979; Thakar and Dave 1986; Fonteh *et al.*, 2005). The use of the LP system is not designed to replace adequate heat treatment, or remove the need for good hygiene practices (FAO and WHO, 2006a), but has application where it is not possible to use mechanical refrigeration for technical, and/or economic reasons. The LP system can play an important role in preventing the spoilage of milk, in many regions of the world where evening milk may be spoiled after storage overnight (Claesson, 1992; Jandal, 1997). The *Codex guidelines for the preservation of raw milk by use of the lactoperoxidase system* [CAC/GL 13-1991] was adopted in 1991 (FAO and WHO, 1991).

milk or milk products post processing. Pathogens such as *Listeria monocytogenes* in particular can survive and thrive in processing environments and contaminate milk and dairy products during or after processing.

The control measures used for chemical and physical hazards in food are generally preventive in nature and focus on avoiding and minimizing their presence rather than elimination at a later stage. In addressing chemical hazards, attention should be given to maintaining a clean production environment and safe feed and water to reduce the potential introduction of chemical contaminants such as dioxins, heavy metals and mycotoxins, as well as implementation of good animal husbandry and practices to ensure that veterinary drugs, pesticides etc. do not exceed levels that would present an unacceptable risk to the consumer.

Procedures and exchange of information are also required to ensure traceability of the product. Codex Alimentarius defines traceability/product tracing as "the ability to follow the movement of a food through specified stage(s) of production, processing and distribution" (FAO and WHO, 2011c). In the event that there is an outbreak of a food-borne illness, those responsible must be able to identify, isolate and recall contaminated product. This often presents challenges both in the highly organized milk and dairy industry in developed countries and in the less-organized, more-informal sector often seen in developing countries. In developed

BOX 6.5

Codex code of hygienic practice for milk and milk products

The *Codex code of hygienic practice for milk and milk products* defines hygienic practices to be applied during the production, processing and handling of milk and milk products and is an important text for producers of milk and milk products. The code proposes a preventive approach with the application of good hygiene practices from production of raw materials (including animal feeds) to the point of consumption. It takes into consideration (as much as feasible) the various production and processing procedures as well as the differing characteristics of milk from various milking animals used by member countries. It focuses on acceptable food-safety outcomes achieved through the use of one or more validated food-safety control measures (FAO and WHO, 2004c).

To achieve a continuum of controls along the chain, the Code recommends that:

- producers should ensure that good agricultural, hygiene and animal husbandry practices are employed at the farm level;
- manufacturers should utilize good manufacturing and hygiene practices, and communicate with milk suppliers any additional measures to be met during primary production;
- distributors, transporters and retailers should assure that milk and milk products in their possession are handled and stored properly and according to the manufacturer's instructions; and
- consumers should accept the responsibility of ensuring that milk and milk products in their possession are handled and stored properly and according to the manufacturer's instructions.

In addition to the application of good hygiene practices, specific guidelines are included for the primary production of milk and management of control measures during and after processing. Additional information is provided on microbiostatic and microbiocidal control measures.

countries, the continuing move to greater volumes of milk from each farm, larger processing facilities and more complex multi-ingredient products (e.g. composite food gels) means that it is increasingly difficult to trace any alleged fault back to the responsible ingredient and then to the farm, to the cow or its feed (Creamer *et al.*, 2002). At the opposite end of the spectrum, tracing products within the informal, highly dispersed production presents difficulties because of the very large number of small-scale producers involved. While the urgency to trace and recall product is particularly acute when product is suspected of being unsafe, effective traceability is an accepted best practice along the dairy chain. Despite the inherent difficulties in milk and animal traceability, the establishment of practical protocols and procedures is an important priority for the dairy industry. If there is no traceability system, or it is weak, it will be difficult to take corrective action when problems are detected.

Countries are encouraged to base national regulations and controls on standards and texts developed by the Codex Alimentarius Commission[54] (see Table 6.6 and the Codex Alimentarius website: http://www.codexalimentarius.org).

TABLE 6.6
Codex Alimentarius standards and related texts for milk and milk products

Codex standards specific to milk and dairy products	
General standard for the use of dairy terms	CODEX STAN 206-1999
Model export certificate for milk and milk products	CAC/GL 67-2008
Guidelines for the preservation of raw milk by use of the lactoperoxidase system	CAC/GL 13-1991
Code of hygienic practice for milk and milk products	CAC/RCP 57-2004
Miscellaneous	
General principles of food hygiene	CAC/RCP 1-1969 (2003)
MRLs for veterinary drugs in foods	CAC/MRL 2-2012
MRLs for pesticides	CAC/MRL 1-2012
Extraneous maximum residue limits (EMRLs)	CAC/MRL 3-2001
General standard for contaminants and toxins in food and feed	CAC/STAN 193-1995
Codex general standard for food additives	CAC/STAN 192-1995
Guidelines on substances used as processing aids	CAC/GL 75-2012
Guidelines for the use of flavourings	CAC/GL 66-2008
Guidelines for risk analysis of food-borne antimicrobial resistance	CAC/GL 77-2011
Guidelines for the design and implementation of national regulatory food-safety assurance programmes associated with the use of veterinary drugs in food producing animals	CAC/GL 71-2009
Code of practice to minimize and contain antimicrobial resistance	CAC/RCP 61-2005
Principles for traceability / product tracing as a tool within a food inspection and certification system	CAC/GL 60-2006
Code of hygienic practice for powdered formulae for infants and young children	CAC/RCP 66-2008
Code of practice for the reduction of aflatoxin B_1 in raw materials and supplemental feedingstuffs for milk producing animals	CAC/RCP 45-1997

[54] The FAO/WHO Codex Alimentarius Commission develops internationally agreed standards and guidelines for safe food that provide the benchmark for food-safety regulation in international trade. These standards can be used as a basis for setting national regulations and setting best practices for the dairy sector. Standards applicable to safety and quality of milk and dairy products are referenced throughout this chapter.

Role of stakeholders

Addressing and managing food-safety risks in milk and dairy products should involve all stakeholders across public and private sectors. This includes farmers, processors, transporters, distributors, retailers and consumers. It is essential that all stakeholders have adequate knowledge and capacity to apply relevant preventive practices and control measures and share relevant information with other actors in the chain. This can present a challenge where there are a large number of individuals or companies in a stakeholder group. The dairy sector in many countries includes a large number of small- to medium-scale dairy farmers widely dispersed in rural areas. To provide adequate support to farmers and overall development of the dairy sector, many countries have built up strong associations and cooperatives providing support on a range of issues, including market access and ensuring a safer, higher-quality product. Specific activities include, but are not limited to, collective transport and marketing and support and advice on safe milk production and hygienic handling, adequate time and temperature controls along the chain and suitable containers and facilities for collection and storage of milk.

Consumers play a key role in ensuring the safety of the final product through such practices as boiling milk before final consumption (where regulations do not require pasteurization) and hygienic reconstitution and storage of milk from milk powder (including preparation of infant formulas). Knowledge and information is essential for consumers to play this role effectively, and manufacturers of milk and dairy products should provide consumers with adequate information on handling and storage of their products. In addition, communication of key food-safety messages about how to protect vulnerable consumers such as infants, immunocompromised people, pregnant women and allergic or nutritionally deficient individuals, requires particular attention.

Officials in the public sector also require adequate skills and information to perform their role of ensuring a safe food supply and providing necessary support to food-chain operators. Government policy and decisions underlying the production of milk and dairy products must be evidence-based and effectively communicated from the food authorities to food-chain operators. The private and public sectors should work together to prevent, reduce or minimize food risks whether through mandatory or voluntary means. Access to information also permits people with the greatest level of risk from any particular hazard to exercise their own options for achieving even greater levels of protection, including avoiding certain high-risk foods. The need for and pace of communication and types of information can change radically when a food-safety emergency occurs and there is a need for increased communication between authorities, industry and consumers to enable tracking and recalling of affected products to protect public health.

Bringing about change and adoption of better practices for food safety should take into account a range of socio-economic factors, in addition to the scientific knowledge of producing a safe product. The most effective governmental control plans to ensure the safety of milk and dairy products will be shaped by several factors, an important one of which is the structure, size and organization of the milk production and processing sector. Challenges include linking producers with markets, compounded by the highly perishable nature of milk and its potential to transmit zoonotic diseases.

6.6 EMERGING ISSUES

Some of the main emerging issues associated with milk and dairy quality and safety include the following:

- The private dairy sector must behave responsibly; the emergence of fraudulent practices resulting in illness and death has given rise to new concerns.
- National food-safety agencies responsible for ensuring the safety and quality of the final product must maintain their vigilance. They must address many food hazards, including those that may be intentionally added, e.g. melamine, addition of whey powder, vegetable fat and maltodextrin in milk powder, and citrate in UHT milk.
- Animal feed quality plays a vital role in ensuring the safety of milk and dairy products.
- There is an increasing demand from consumers for raw milk and dairy products produced from raw milk. This poses new challenges for regulatory authorities where pasteurization in mandated, and calls for a re-assessment of production practices to ensure the safety of these products.
- Emerging pathogens, including *Cronobacter* spp. and MAP, require further investigation to determine the risk to consumer health.
- Debate around the acceptable use of veterinary drugs in animal husbandry including establishment of agreed international standards continues.
- Anti-microbial resistance caused by over or inappropriate use of antimicrobials in the animal health sector (in addition to antibiotics used in treating human diseases) is an emerging public-health concern. Although milk that is pasteurized or treated to destroy bacterial contaminants is very unlikely to be a vector for drug-resistant bacteria, unpasteurized milks may be a vector.

6.7 KEY MESSAGES

6.7.1 Safety of milk and dairy products

The safety of milk and dairy products must be ensured to protect consumers, particularly vulnerable consumers such as children for whom milk can be a beneficial dietary component, and to support the livelihoods of dairy farmers and processors.

Raw or poorly processed and/or handled milk and milk products can lead to food-borne illness in humans. Pasteurization or equivalent processing of milk and milk products and the implementation of validated food-safety programmes have been proved to ensure safe milk and dairy products.

A great deal is known about the sources of hazards that can compromise the safety of milk and dairy products and the necessary controls and preventive measures to ensure products are safe. The risk-reduction measures required vary with the hazard and the intrinsic product characteristics so that while it may not always be necessary to eliminate the hazard completely, its presence must be minimized to provide an acceptable level of consumer protection. Raw milk or raw-milk products should be individually assessed for their potential risk to public health and appropriate risk-management strategies implemented.

There is increasing evidence of the importance of the safety of animal feeds and the natural environment where animals graze/live in preventing chemical hazards including dioxins.

Labelling of milk and dairy products should be clear, informative and include food-safety messages when required.

6.7.2 Prevention/control

Food-safety hazards can be introduced to milk and dairy products at various points of the food chain. To minimize the health risks of milk and dairy products at the point of consumption, all food-chain operators, including the dairy farmer, processor, distributor, retailer and consumer, need to take necessary actions to maintain food-safety.

Several factors have a bearing on food-safety risks of milk and dairy products, including farm practices, the initial quality of the raw milk, the type of product (e.g. liquid milk versus cheese or ice cream), processing technology, processing and storage conditions and availability of facilities, hygiene practices, the level of sophistication/maturity of the dairy industry and prevailing local socio-economic conditions.

A comprehensive risk-based preventive approach is required, from farm level (animal feed, milking and milk storage), through to processing, marketing and consumption, identifying those points where control measures are likely to have the greatest impact on protecting the consumer.

Vigilance and monitoring by risk managers are required to ensure effective controls and conditions for safe production and storage of milk and dairy products. These need to be specific to the product and production environment.

While the causes of food-safety risks in the milk chain are similar everywhere, the actual causes do vary between developed and developing/transition countries. For example, the transmission of brucellosis and tuberculosis can be common in countries where control of animal diseases is poor and milk pasteurization or an equivalent is not practised or is poorly implemented.

Food-preservation practices need to be effective as well as appropriate to the local setting. For example, where pasteurization is not feasible, LP may be used in some countries.

Governments have a key role to play in engaging with all stakeholders to establish national controls and standards, including inspection and surveillance to ensure that the private sector is providing safe product and guidance for the public sector.

6.7.3 International guidance/controls

The international Codex Alimentarius standards are a reference for quality parameters and safety requirements, including hygiene practices to be in place along the commodity chain. Food-chain operators are encouraged to base their controls on these standards.

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The author declares that no financial or other conflict of interest exists in relation to the content of the chapter.

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Chapter 7

Milk and dairy programmes affecting nutrition

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ABSTRACT

A systematic review was undertaken to examine the evidence for the effects of milk and dairy programmes on nutrition. Twenty-nine evaluations and studies were identified and rated based on quality of design and level of inference, in ascending order: observational/formative (5); adequacy (10); plausibility (8); and probability (6). The chapter describes the typical model, evidence for impact, and lessons learned for four programme types: dairy production and agriculture programmes; school-based milk programmes; fortified milk programmes; and milk powder and blended foods. Dairy production programmes were found to be more effective than traditional agriculture production interventions if strategies included: targeting inputs to women; the introduction of small livestock; and communication about the nutritional value of milk. School-based programmes improved body composition and micronutrient status, but issues of appropriate levels of fat, added sugar and flavouring in milk need to be addressed. Evidence for positive nutrition outcomes was strongest from fortified milk programming, though issues of limited market access, cost, and questionable effects on zinc nutrition remain. Finally, milk has been added to blended foods for decades but the effect of the milk ingredient is largely unknown. To conclude, dairy programming faces many challenges including the need for higher-quality evaluations that assess cost-effectiveness and consideration of the dual burden of under- and overnutrition. The findings demonstrate that milk and dairy programmes can simultaneously improve nutrition and reduce poverty, aided by the generally positive public perception of milk. With planning and investment, milk may contribute to improving the health and well-being of many globally.

7.1 INTRODUCTION

Micronutrients are vitamins and minerals required by the body in small quantities to sustain health and well-being. Deficiencies in some micronutrients, including vitamin A, iodine, iron and zinc, contribute significantly to global burden of disease (Black *et al.*, 2008). Vitamin A deficiency affects 190 million preschool-aged children and 19.1 million pregnant women (WHO, 2012), elevating the risk for night blindness, infection and mortality (West, 2002). One-third of world's population is thought to be deficient in zinc, now known to increase diarrhoeal morbidity and mortality (Hess *et al.*, 2009). Iodine deficiency, the leading cause of mental retarda-

tion globally, affects 36.5 percent of school-aged children (WHO, 2012). Anaemia is estimated to affect 1.62 billion people and is most widely prevalent among preschool-aged children (47.4 percent) and pregnant women (41.8 percent) (WHO, 2012). The condition may arise from multiple causes, several of which are related to dietary deficiencies in iron, vitamin A and B_{12}, folate, riboflavin and copper, and can lead to impairment of cognitive and physical development in young children, poor birth outcomes in pregnant women and, in severe cases, increased risk of mortality in certain populations (Hoffbrand, Moss and Pettit, 2006).

Poor diets and high infection burden are the primary causes of micronutrient deficiencies in developing countries. Diets often lack animal-source foods (ASF) that provide several critical micronutrients in more bio-available forms than are available in plant-based diets (Demment, Young and Sensenig, 2003; Murphy and Allen, 2003).

Milk is an excellent source of both macro- and micronutrients, as discussed in Chapters 3 and 4. It is high in energy, lipids and high-quality proteins. Milk also contains nutrients critical for growth and development, including calcium, vitamin A, riboflavin and vitamin B_{12} (Hoppe *et al.*, 2008). Insulin-like growth factor, found in milk, is also known to promote linear growth (Hoppe, Mølgaard and Michaelsen, 2006).

In some countries, both under- and overnutrition are prevalent in the population and even within the same household. The causes of this are multifactoral and related to changes in dietary patterns towards more energy-dense foods, increasing urbanization and lifestyle changes that are reducing physical activity (WHO, 2003; Pdairopkin, 2006). There is some evidence linking food-supplementation programmes in Latin America with weight gain above the reference median (Uauy, Albala and Kain, 2001). However, milk programming has not been implicated in increasing obesity, though an awareness of the problem is needed moving forward. The association between dairy intake and weight gain and obesity is examined in detail in Chapter 4.

There is widespread consensus and strong evidence now showing that undernutrition during the first two years of life is a strong predictor of child mortality (Black *et al.*, 2008) and that, among those who survive, early childhood malnutrition has long-term, serious health and developmental consequences (Victora *et al.*, 2008). Interventions targeting infants and young children are widely recognized to be the most effective in terms of increasing child survival and improving growth (Bhutta *et al.*, 2008).

This chapter focuses on milk programmes affecting undernutrition, as the major challenge in developing countries for young children in particular. A review of the literature is presented covering four major programme types: dairy production and agriculture programmes; school-based milk programmes; fortified-milk programmes; and milk powder and blended foods. Under each programme type, there is a brief description of the typical programme model, followed by an overview of the evidence-base linking the milk-related interventions to nutrition. Most of the programmes reviewed in three of the categories (dairy production and agriculture programmes, fortified-milk programmes and milk powder and blended foods) targeted children less than five years of age. School-based milk programmes were generally aimed at improving nutrition for primary-school-aged children, 6–11 years.

7.2 SOURCES AND APPROACH TO THE REVIEW

A comprehensive review of the peer-reviewed and grey literature was conducted to identify milk programmes affecting the nutrition of populations in developing countries. "Milk programme" was defined as an intervention introduced into a defined population over a certain period of time that involved milk and affected nutrition in some manner. Databases searched included: Proquest; PubMed Central; Science Direct; and Scopus. Coverage was global, although most records were in English. In addition, web pages from several international agencies and non-governmental organizations were searched for grey literature, monographs and evaluations. Both simple and multifield/advanced searches were used. The following criteria were used to decide whether to include a programme in the study: 1) milk or dairy products were part of the intervention; 2) nutrition, and in some cases health and anthropometry of participants, was affected through the diet; 3) the study was intended to inform programming (observational/formative) or included an evaluation that allowed the possibility of inferring adequacy, plausibility or probability (see following paragraph); and 4) the programme context was a developing country.

Programmes were classified into four levels of inference, to indicate quality of design and methods. These were, in ascending order of rigour: 1) observational/formative; 2) adequacy; 3) plausibility; and 4) probability (Habicht, Victora and Vaughan, 1999). Observational/formative includes those results and findings that are intended to inform programming strategies or are later used to do so. No conclusions may be drawn on intervention impact. Adequacy includes studies or evaluations assessing only whether expected changes occurred. There is usually no control group, but at least two surveys or measures over time and space are carried out to assess change. The next level of inference is plausibility, in which factors operating to influence outcome beyond the programme intervention may be considered. Some form of control group (historical, internal or external) is generally used in these quasi-experimentally designed evaluations. The highest level of inference possible is probability, where the evaluation design is likely to be able to demonstrate causality. Programme intervention may be linked to outcomes with a low probability of confounding, bias or chance. Randomized controlled trials (RCTs) have been the gold standard for this inference, though different techniques and evaluation designs are becoming more widely accepted to establish attribution (Victora, Habicht and Bryce, 2004).

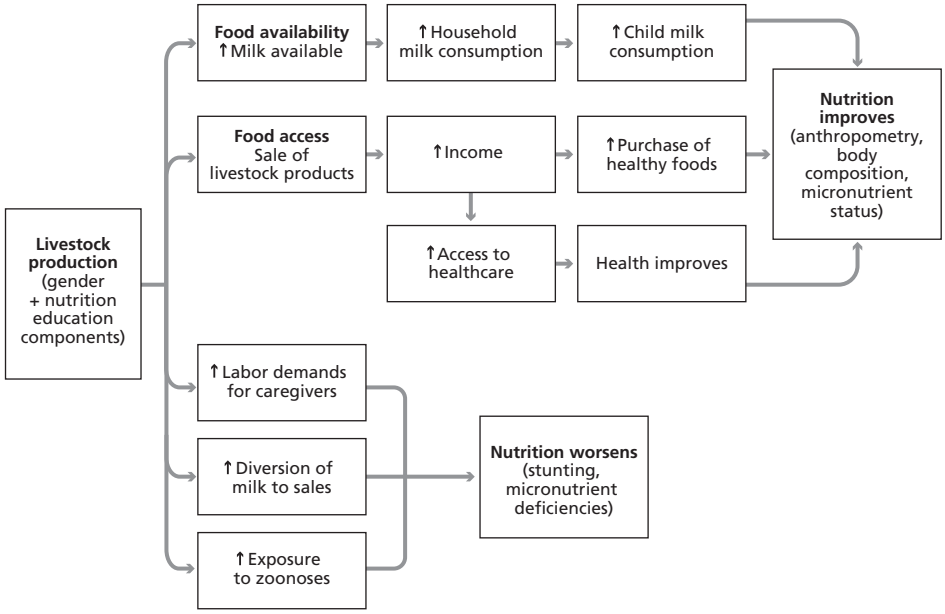
Table 7.1 (see Annex) summarizes the programmes reviewed in each of the four categories. Programmes are organized alphabetically by country name within regions and then chronologically by date if there was more than one programme or study per country.

7.3 DAIRY PRODUCTION AND AGRICULTURE PROGRAMMES

Nutrition is most likely to be affected by dairy production programming via two pathways: increased milk availability from production leading to increased direct consumption; and improved access to higher-quality foods as a result of increased income (Figure 7.1). Whether diet improves as a result of increases in income depends on the recipient's understanding the need for good nutrition; if they do not, the additional income may be used to buy more of the same foods or foods of lesser quality. Other possible negative effects of dairy production on nutrition

FIGURE 7.1
Impact pathways for various types of milk and dairy programmes affecting nutrition

a. Dairy production and agriculture programmes



b. School-based milk programmes

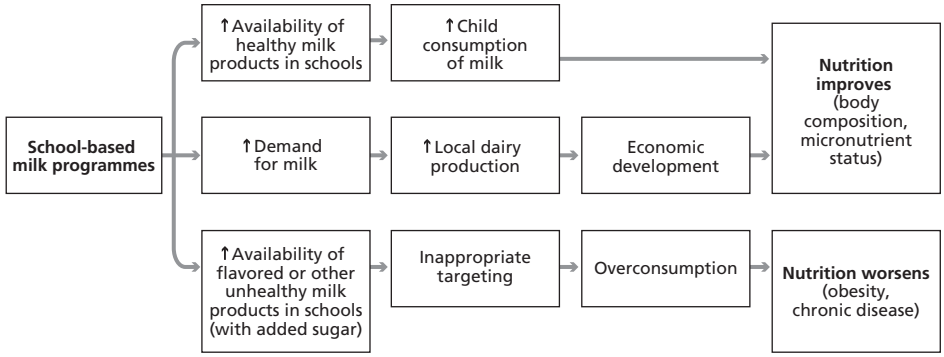
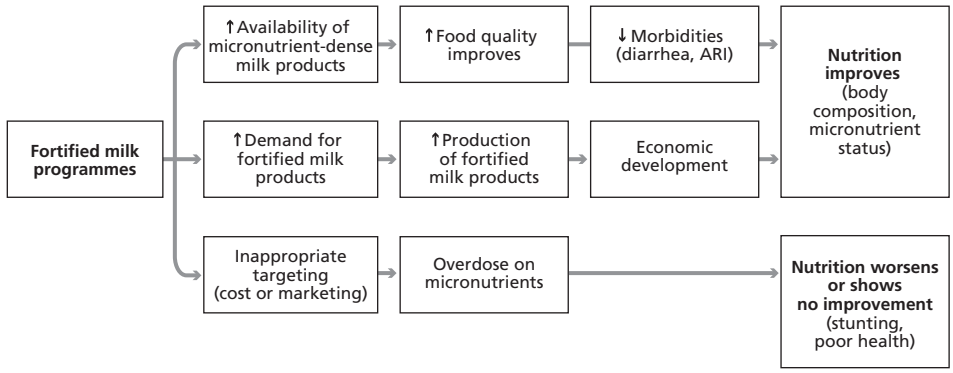
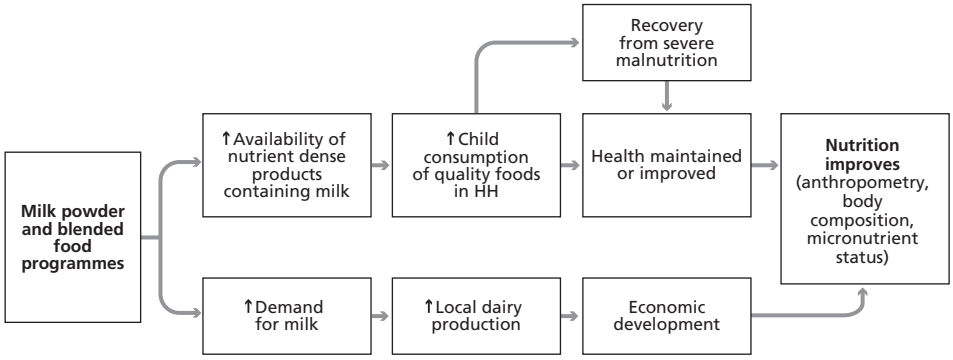


FIGURE 7.1 *(continued)*

c. Fortified milk programmes



d. Milk powder and blended food programmes



Source: Iannotti, Muehlhoff and McMahon, 2013

include increased labour demands on childcare providers, diversion of milk for sale and exposure to zoonoses. Previous reviews have explored these pathways in the broader categories of agricultural production (Berti, Krasevec and FitzGerald, 2004; World Bank, 2007) and livestock development (Tangka, Jabbar and Shapiro, 2000; Leroy and Frongillo, 2007; Randolph *et al.*, 2007).

World Bank (2007) identified five pathways from agriculture to nutrition: subsistence-oriented production for household's own consumption; income-oriented production for sale in markets; reduction in real food prices associated with increased agricultural production; empowerment of women as agents instrumental to household food security and health outcomes; and an indirect relationship

between increasing agricultural productivity and nutrition outcomes through the agriculture sector's contribution to national income and macroeconomic growth. The report finds that most information about agricultural programming pertains to changes in food availability and access, and very little to direct nutrition outcomes. It concludes that in order to successfully influence nutrition, agricultural programmes should more broadly address women's empowerment, behavioural change and health, and incorporate specific, targeted nutrition and health interventions. Berti, Krasevec and FitzGerald (2004) also found that interventions with explicit nutrition objectives and those including investments in human capital inputs (nutrition education and gender) were more likely to show positive nutrition outcomes.

Tangka, Jabbar and Shapiro (2000), Leroy and Frongillo (2007) and Randolph *et al.* (2007) also found that livestock interventions improve production and income, but such programmes often do not have evaluations capable of demonstrating impact on dietary intakes or nutritional status. Positive impacts on "intermediate" outcomes (production, income and dietary intake) do indicate the potential for improving nutrition through increasing livestock production and highlight the need for better-designed evaluations and cost-benefit analyses (Leroy and Frongillo, 2007). Tangka, Jabbar and Shapiro (2000) cite several observational studies that link ownership of milk-producing livestock to improved child nutrition outcomes. These reviews did not conduct meta-analyses of original study data, and did not assign comparative quality ratings, as was done in the present review.

Eleven dairy production and agriculture programmes were included in this review, seven from sub-Saharan Africa and four from Asia. Six of the programmes were not included in the five previous reviews described above: Ayalew, Gebriel and Kassa (1999), Ayele and Peacock (2003), Hop (2003), Cunningham (2009), Iannotti, Cunningham and Ruel (2009) and Sadler and Catley (2009). The typical programme model involved only production strategies such as improved animal feeding (e.g. zero-grazing) or the introduction of cross-breeds. Some programmes introduced a gender component either through targeting women for dairy production inputs or use of female extension workers. Others incorporated more explicitly nutrition-related strategies in the dairy production inputs, including behaviour change communication, promotion of milk consumption and, in the case of Viet Nam, policy-level links between agriculture and nutrition goals. Finally, some programmes applied a more comprehensive, multidisciplinary approach combining agriculture, health and nutrition interventions.

7.3.1 Africa

In the Kilifi District of Kenya, a national dairy development project (DDP) initiated in 1980 and supported by the Netherlands Government aimed at improving dairy management practices primarily through the introduction of "zero-grazing" or keeping cattle permanently in stables (Hoorweg, Leegwater and Veerman, 2000). A study was conducted to assess whether households participating in the DDP since before 1985 (group 1; n=30) or dairy customers of DDP farmers (group 2; n=24) showed higher levels of milk consumption and improved anthropometry of young children (6–59 mo) compared with a control group of rural households (group 3; n=90). Using a 24-hour dietary intake recall, the study showed that milk consumption was higher in DDP farmer and customer groups than in control households and that height-for-

age and weight-for-age Z-scores were higher among children from households of DDP farmers and customer groups than those from control households.

The Dairy Technology Project in Ethiopia, a collaborative project between the Ethiopian Agricultural Research Organization (EARO) and the International Livestock Research Institute (ILRI) introduced cross-bred cows and improved feeding and dairy management technologies. Data collected by EARO and ILRI from 1995–1996 was analysed to assess whether there were any improvements in income, patterns of food and non-food expenditures and calorie intakes (Ahmed, Jabbar and Ehui, 2000). A cross-sectional study was carried out comparing wealth-matched groups of participating households with cross-bred cows and non-participating households using traditional practices. Using econometric modelling and a thorough accounting for important confounding variables such as seasonality and wealth, the authors found that ownership of cross-bred cows and adoption of new dairy technologies were associated with higher income, household food expenditures and energy intakes. The increase in income was found to translate directly into increased per capita energy intakes. Intrahousehold allocation of food was not considered, and no milk-specific findings were identified. Both this study and Hoorweg, Leegwater and Veerman (2000) received a plausibility ranking level of inference because control groups were used in quasi-experimentally designed studies in an effort to adjust for external factors influencing outcomes.

Dairying is predominantly managed by women in East Africa, but access to dairy inputs (land, fodder, credit, etc.) and control of dairy income is not necessarily available to women. Studies from Kenya (Mullins and Wahome, 1996) and the East African highlands (Tangka, Ouma and Staal, 1999) reinforced the findings from the World Bank (2007) review that highlighted the importance of gender-based objectives and interventions for achieving nutritional outcomes. Mullins and Wahome (1996) found that using female extension workers to reach women made it more likely that proceeds from dairy enterprise went to women, and that the income from the enterprise was used to pay for schooling and food. Tangka, Ouma and Staal (1999) found that in Kenya, although market-oriented smallholder dairying increased demands on women's labour, it compensated for this through increases in income that remained under women's control. Contrary to previous findings, the authors conclude that commercialization of smallholder dairying increases the livelihoods of women in East Africa (Tangka, Ouma and Staal, 1999). These studies received only an observational/formative rating, but still provide insight into the importance of gender.

The Dairy Goat Development Project (DGDP) in Ethiopia, implemented by FARM-Africa (Ayalew, Gebriel and Kassa, 1999; Ayele and Peacock, 2003) is a widely-cited small livestock programme designed to improve nutrition. The project was introduced in 1988 when goats were recognized as being an important part of mixed farming systems in the country. The DGDP was developed to "improve family welfare through generating increased income and milk consumption" (Ayele and Peacock, 2003). This project uniquely included an explicit nutrition objective: "increase the consumption of milk by children, thereby improving their intake of vital micronutrients, such as vitamin A and zinc". It also targeted female-headed households and sought to empower women through "development of leadership skills and improved technical knowledge". FARM-Africa evaluated this project

using a pre- and post-intervention design to look at programme outcomes related to income and milk consumption. Only adequacy inference is possible from this design. Some process-evaluation data were also collected to look at goat production. Using the Helen Keller International (HKI) food frequency questionnaire, they determined that children in the 39 households surveyed in Gorogutu District consumed milk more frequently following the intervention. In Gursum District, FARM-Africa found that more than 85 percent of the intervention households, especially young children, consumed the goat milk they produced.

While there were several positive nutrition-related outcomes such as increased milk consumption and other dietary intake improvements, the DGDP was not able to demonstrate effects on clinical signs of vitamin A deficiency. In December 1995, a new trial was developed to test whether adding an integrated package of interventions to DGDP, including more-concerted efforts to promote vitamin-A-rich foods such as goat milk, would better achieve the nutrition outcomes (Ayalew, Gebriel and Kassa, 1999). Formative research was conducted to develop nutrition messages, and an integrated package that involved working through women's groups and delivering messages through community education, radio and television broadcasts, and the intervention was implemented from December 1996 to August 1997. Again, a pre-intervention (February–March 1996) and post-intervention (January–March 1998) design was used for evaluation. In addition to the limitations imposed by this adequacy-level design, 32 percent dropout rate and compromised intervention integrity (33 percent maintained the same pattern of goat ownership while others acquired new goats or lost the original goats) posed serious problems for analyses.

The results showed that diversity of children's diet was greater in the post-intervention period than pre-intervention (Ayalew, Gebriel and Kassa, 1999). In the goat-owning households, all the milk produced was consumed. However, investigators found that goat ownership alone did not reduce risk of vitamin-A deficiency but that milk consumption and income from agricultural sales were inversely related to vitamin-A deficiency. These results further reinforce the need for more integrated, comprehensive intervention packages.

Participatory research carried out in Liben and Shinile, Ethiopia, prior to developing interventions to promote milk consumption (Sadler and Catley, 2009) demonstrated that Somali pastoralists' have a strong appreciation for milk (Randolph *et al.*, 2007). Milk supplied two-thirds of energy and 100 percent of protein for young children around one year of age. Children's milk consumption varied between seasons and fell during droughts. The communities identified interventions to improve animal health (fodder production, increased water supply and veterinary care) as a means to ensuring adequate supply of milk for consumption (Sadler and Catley, 2009).

7.3.2 Asia and the Pacific

The VAC system is a traditional farming approach in Viet Nam that incorporates environmental, ecological and nutritional principles. V stands for *vuon* or garden (all land cultivation activities), A for *ao* or pond (all aquaculture), and C for *chuong* or cattle shed (all animal husbandry). Since 1989, there have been positive trends nationally in poverty reduction, agricultural production, socio-cultural, environmental, and health outcomes (Hop, 2003). This ecological study of secular

trends, ranked as observational/formative, could not directly link VAC with positive nutrition outcomes, although increases in ASF consumption and decreases in underweight, stunting, and anaemia have been observed over the last two decades since its inception (Hop, 2003).

The dairy programme, Operation Flood, in India has received considerable attention and was included recently among the Millions Fed case studies as a successful initiative to reduce food insecurity in India (Cunningham, 2009). Operation Flood aimed to create a "milk grid" that connected rural, small-scale dairy producers to urban areas through sophisticated procurement systems. Village-level cooperatives were established to help link smallholders, 80 percent of whom owned two to five cows, to urban consumers. Cross-bred cows were introduced as well as other processing inputs such as silos, pasteurizers, storage tanks and refrigerators. Another innovation of the programme was the use of food-aid milk powder in the supply chain during seasons of low domestic milk production. Cunningham (2009) examined district and national level data from before and after the programme and concluded that "the growth in production has made milk increasingly available to consumers, providing an important source of nutrition for millions of people". The study was not designed to examine the impact of dairy (or income derived from dairy) on nutrient intake and the nutritional levels of participating households.

Also in India, the Karnataka Dairy Development Project was launched in 1974 to support development of village cooperatives aimed at increasing production through improved animal nutrition and cross-breeding. A well-designed study, classified at plausibility level of inference, demonstrated that there was increased nutrient intake among dairy-producing households (Alderman, 1987). The presence of a cooperative tended to reduce milk consumption, largely as a result of increases in prices, but the nutrient intake of milk producers increased because their income increased. In contrast, increases in the prices of rice and ragi reduced nutrient intakes. The author concludes that "There appears to be less need for concern about the effects of local milk prices on nutrition than about the effects of local cereal prices on nutrient intake". No behaviour-change communication/nutrition education component was included in this project.

Another case study from the Millions Fed project was the Homestead Food Production (HFP) programme of HKI (Iannotti, Cunningham and Ruel, 2009). HFP includes interventions to increase food production through agriculture and livestock inputs, increase knowledge and awareness through behaviour change, improve health through establishing linkages with health services and empower women through control of resources. Largely through the use of pre- and post-evaluation design and achieving only adequacy level of inference, HKI has found that HFP is associated with improved dietary quality and diversity both through increased income and wealth and increased availability of ASF through own production pathways. It is estimated that the food security of approximately 5 million people in Bangladesh has improved as a result of the programme. However, HFP programmes have not yet been shown to have a meaningful impact on nutritional status as measured by anthropometry or markers of micronutrient nutrition (Iannotti, Cunningham and Ruel, 2009).

7.3.3 Summary

This section covered the findings from five previous reviews – two on agriculture and nutrition (Berti, Krasevec and FitzGerald, 2004; World Bank, 2007) and three focused on livestock development and nutrition (Tangka, Jabbar and Shapiro, 2000; Leroy and Frongillo, 2007; Randolph *et al.*, 2007) – and six additional studies examining more specifically milk and dairy programmes affecting nutrition.

The first programming strategy emerging from these studies relates to gender. Women were shown to be primarily responsible for dairying in East Africa in particular, and, when targeted, use income earned for schooling and food for children (Mullins and Wahome, 1996; Tangka, Ouma and Staal, 1999). The introduction of improved breeds of cows and goats was associated with increased milk production and in some cases increased consumption (Alderman, 1987; Ayalew, Gebriel and Kassa, 1999; Ahmed, Jabbar and Ehui, 2000; Ayele and Peacock, 2003). One potential challenge with this type of programming, however, is the considerable investments required upfront for raising large animals, i.e. dairy cows, especially in terms of infrastructure (animal health services) and other inputs (especially feed). This may result in selection bias towards households having a better economic (and likely nutritional) status. Programme inputs to offset these costs for poor households may therefore also be needed.

Programmes that established market linkages were associated with increased income and milk consumption (Tangka, Ouma and Staal, 1999; Cunningham, 2009). The formation of cooperatives facilitated the market connections for smallholder dairy farmers (Cunningham, 2009). Finally, studies and evaluations have shown the importance of awareness and understanding of the nutritional value of milk for vulnerable groups. While some communities (e.g. pastoralist communities) already have an appreciation of the nutritional value of milk (Sadler and Catley, 2009), in other contexts nutrition education, including behaviour-change communication, will need to be included in programming in order to raise awareness of the nutritional value of milk (Iannotti, Cunningham and Ruel, 2009).

7.4 SCHOOL-BASED MILK PROGRAMMES

School-based milk programmes are common in many countries around the world. Support for these programmes is often built on the assumption and public perception that milk is a nutritionally advantageous food for children. There is still a need to evaluate the nutritional outcomes of such school-based interventions more systematically and for more effective targeting to specific groups of children. Studies at the beginning of the twentieth century in Scotland were among the first to show that milk delivered to school-aged children increased height (Orr, 1928). Later studies showed that the greatest height increase was realized if milk were targeted to undernourished children (Hoppe, Mølgaard and Michaelsen, 2006). Additional information is provided in Section 4.3 of Chapter 4.

On the last Wednesday in September, countries around the world celebrate World School Milk Day. The event, started in 2000, is now held in over 30 countries, bringing attention to school-based milk programmes and promoting milk among the students (FAO, 2011). In many countries, high-level dignitaries are present at School Milk Day events and speak in support of school milk. Contests are often held among the students, and most countries involve the media to promote pro-

grammes and milk consumption more generally. Some of the festivities from 2009 included the launching of School Milk Clubs in various schools in Gujarat, India; articles about school milk published in magazines and newspaper in Indonesia; the gathering of children and representatives from dairies in the main square of Zagreb, Croatia; and an event attended by the Regional Commissioner of Kilimanjaro, the Chairman of the Tanzania Dairy Board, representatives from the Ministry of Livestock Development, pupils, parents and others in Tanzania (FAO, 2011).

In 1998, the FAO Commodities and Trade Division conducted a survey with members of the International Dairy Federation's International Milk Promotion Group to determine the current situation of milk in schools around the world (Griffin, 2004). Thirty-six countries responded. In general, school milk programmes have been supported by both public funding and more recently by the dairy industry. The survey found that school milk represents relatively large percentages of the milk market (3–25 percent). The survey did not ask specifically about whether countries had determined the nutritional impacts of milk in schools, but several questions did begin to probe for this effect. Some countries reported distributing free milk to children less than five years old in nursery schools (Argentina, Finland, Kenya, Malawi, Moldova, Portugal, Sweden, Thailand, the United Kingdom and the United States), an important age when children are particularly vulnerable to nutritional deficiencies, which can have long-term consequences for them.

Milk is perceived to be nutritious for school-aged children and thus more widely promoted than other beverages; 74 percent of countries responding to FAO's survey reported promoting milk in schools (Griffin, 2004). Approximately one-fifth of the countries use educational resources to promote milk. The campaign emphasizes the value of milk in terms of particular nutrients such as calcium. This may be viewed as an opportunity for achieving positive nutritional outcomes from school-based milk programming, given the receptivity and general awareness that seems to be present already. One challenge will be the competing beverages that are also present in schools. The FAO survey revealed that sugar-sweetened beverages, including fruit juice (34 percent) and carbonated drinks (28 percent), were the most-commonly reported alternative drinks to milk available in the schools, and that these products are also promoted (Griffin, 2004). Given the rising obesity problem in children around the world and the associated increase in type II diabetes among young people (UNICEF, 2007; WHO, 2011), it may be important to promote reduced-fat milk in schools and discourage availability and consumption of sugar sweetened drinks (Popkin, 2006).

7.4.1 Studies in Kenya and China

Two well-designed studies from Kenya and China, assigned the higher level of plausibility inference, provide insight into the potential nutritional benefits associated with school-based milk programmes.

The school-based study in Embu District, Kenya, aimed at investigating the effect of ASF, particularly meat and milk, on growth, cognition and physical activity in school-aged children (6–14 years). Children in the intervention groups received a mid-morning snack while school was in session for a total of 23 months over a two-and-a-half-year period. Children in the three intervention groups were served a local dish called *githeri* made with maize, beans and greens. Group 1 received the

dish with minced beef, group 2 with ultra-high temperature (UHT) cow milk and group 3 with added oil.

All intervention groups gained more weight than the control group, with the greatest effects among young children, boys and those with lower socio-economic status (SES) (Grillenberger *et al.*, 2003). Milk supplementation had the greatest impact on height gain among children stunted at baseline; children in this substratum receiving daily milk showed a 1.3 cm greater increase in height (15 percent) than the control group. Children in the meat group had the greatest increase in mid-arm muscle area, followed by those in the milk group (Grillenberger *et al.*, 2003; Neumann *et al.*, 2007). Children in the milk group demonstrated a significantly lower rate of increase in Raven's Progressive Matrices, a measure of cognitive development, than the other groups (Neumann *et al.*, 2007). No significant differences were observed for the verbal meaning and digit span tests, but the milk and control groups performed significantly worse in the arithmetic tests than the other intervention groups. It should be noted that baseline milk consumption in this population was not accounted for and may have influenced outcomes.

The other well-designed study of school-based milk distribution was conducted in China from 1999 to 2001 (Du *et al.*, 2004). Nine schools were matched on SES characteristics and randomly assigned to three groups. Pre-adolescent 10-year-old girls participated in the trial. Girls in group 1 received 330 ml of milk each school day for two years. Girls in group 2 received the same amount of milk supplemented with cholecalciferol (15 µg/litre in the first two batches of milk, 24 µg/litre in the last four batches). Group 3, the control, received no supplementary milk. Girls receiving milk with or without cholecalciferol showed significant increases in growth and bone mineral content and density compared with the control group. Those receiving milk with cholecalciferol had greater increases in bone mineral content and density than those who received milk but no cholecalciferol. A follow-up study three years after the supplementation trial ended demonstrated a sustained height effect (sitting height), but no significant differences in vitamin D status (Zhu *et al.*, 2006).

Both of these studies, which used a strong quasi-experimental design, provide important contributions to the evidence base for milk and nutrition in school-based programming.

7.4.2 Asia and the Pacific

School-based milk programmes appear to be more widely supported through governments and public funds in the Asia and Pacific region than elsewhere. While several programmes reviewed do include nutrition objectives, there is limited information concerning nutrition impacts. One study in Viet Nam evaluated the impacts of a large-scale school nutrition programme supplementing primary school children with milk and a wheat flour biscuit (Hall *et al.*, 2007). This cluster-designed study, which achieved a plausibility ranking, compared growth of children in grade 1 of primary schools offering a snack of 200 ml of UHT milk fortified with vitamins A and D together with a fortified wheat biscuit with that of children in grade 1 primary schools without the supplementation programme over a 17-month period. Only gains in weight remained statistically significant after controlling for other variables including school clustering (Hall *et al.*, 2007). Unfortunately, the effects of the milk alone could not be separated from the biscuit because of the study design.

Other programmes identified focused on coverage estimates rather than evaluating or comparing nutrition outcomes across programme intervention and non-intervention schools (Habicht, Victora and Vaughan, 1999), and thus fall into the category of adequacy inference only. A programme in Mongolia explicitly highlighted the problem of undernutrition and micronutrient deficiencies among primary-school children, emphasizing heightened vulnerabilities due to harsh winters and remote areas (CFC, APHCAP and FAO, 2008). Children in a particularly remote area of the Gobi Desert benefit from the Bayenlig Primary School milk programme that supports a camel-herder group. Another programme in Teajam, North Korea, similarly supports local goat milk production and processing (CFC, APHCAP and FAO, 2008).

The National School Milk Programme in Thailand, administered by the Ministry of Agriculture's Livestock Bureau, was designed to build up the local dairy industry. Initiated in 1983, the programme set out to create a demand among children by establishing milk-consumption behaviour in school. A review of the programme by the Institute of Nutrition, Mahidol University, found that students in the programme consumed more energy, protein, calcium and vitamin B_{12} than the usual diets provide, and that there was a suggested, unadjusted impact on height (Smitasiri and Chotiboriboon, 2003). Another study conducted by the National Youth Bureau and Department of Education, Kasetsart University, compared health and motor activity outcomes among participating and non-participating children in Bangkok schools and found that children receiving milk were taller than those attending non-programme schools, but found no differences in motor fitness (Smitasiri and Chotiboriboon, 2003).

7.4.3 Summary

School-based milk programmes are common in many parts of the world and enjoy growing popularity among governments and the school community in countries that have ready access to dairy commodities from national production. There appears to be widespread consensus on the nutritional value of milk for school-age children. A survey by FAO in 1998 found that three-quarters of responding countries promote milk in schools through a variety of methods such as education and milk campaigns (Griffin, 2004). These findings and others suggest receptivity to school-based milk programming specifically aimed at improving nutrition. Of the six school-based milk programmes or studies reviewed, three were classified as adequacy level of inference and three as plausibility. The studies in China and Kenya, which had the strongest designs, demonstrated important impacts of school feeding on linear growth (Du *et al.*, 2004; Neumann *et al.*, 2007), body composition (Neumann *et al.*, 2007) and micronutrient status (Du *et al.*, 2004). A large school programme in Viet Nam suggested some potential for impact on growth, but was not able to differentiate the effect of milk from a wheat flour biscuit also provided by the programme (Hall *et al.*, 2007). Another potential opportunity associated with school milk programmes evident in this review is the support provided to local dairy industry (FAO, 2011). This may further ensure governmental and industry support to the programmes.

Some challenges lie ahead for school-based milk programming. In view of the growing problem of obesity, consideration should be given to the kinds of milk

offered in schools, including fat content and flavouring. Little evidence is available as a basis for this kind of decision-making in developing countries. There is some evidence from developed countries in different age groups, though, showing that fat levels in milk do not markedly affect either the bio-availability of vitamin A and E (Herrero-Barbudo *et al.*, 2006) or plasma levels of polyunsaturated fatty acids (Svahn *et al.*, 2002). As with the dairy development and agriculture programmes, there is a need for better-designed effectiveness evaluations of nutrition outcomes with this programme type.

7.5 FORTIFIED-MILK PROGRAMMES

Fortified foods can be a cost-effective way to deliver important nutrients. Milk has been used in several large-scale programmes as a vehicle for fortification and improving micronutrient nutrition in populations. Some barriers to nutrition impacts from food fortification include: technology limitations and cost; nutrient–nutrient interactions; bio-availability of some fortificants; acceptability and palatability of fortified foods; and difficulty in fortifying widely consumed staples such as rice (Allen, 2003). This section deals with efforts to modify the nutrient content of milk in order to improve its nutritional quality and address particular nutrient deficiency problems.

7.5.1 Latin America and the Caribbean

Much of the evidence for efficacy and effectiveness of milk fortification for improving nutrition outcomes in the developing regions comes from Latin America. Several countries in this region, including Chile and Mexico, have first studied the potential for nutrition impacts from milk fortification and then translated the findings into larger-scale programmes. These efforts focused on iron and zinc because milk contains relatively small amounts of these nutrients, and iron and zinc deficiencies are prevalent in vulnerable populations around the region.

One well-designed randomized, controlled study in Chile during the 1980s, ranked at the highest level of probability inference, paved the way for later fortification programmes (Stekel *et al.*, 1988). This study compared iron nutrition and anaemia outcomes among young children who had received a supplement of either full-fat milk fortified with micronutrients (ferrous sulphate, ascorbic acid, vitamin A and vitamin D) or non-fortified full-fat milk from 3 to 15 months of age. Data collected during follow-up at 9 and 15 months of age demonstrated positive impacts on markers of iron nutrition including transferrin saturation and serum ferritin, and reduced prevalence of anaemia in the intervention group compared with the control (Stekel *et al.*, 1988). Other studies not included in this review have also found positive effects of iron-fortified milk targeted to vulnerable population groups with anaemia and low iron status (Iost *et al.*, 1998; Virtanen *et al.*, 2001).

The National Complementary Food Programme (NCFP) in Chile began as a public milk-distribution programme during the 1920s (Uauy, Albala and Kain, 2001). The original goal was to promote growth and development early in life by providing food supplements to pregnant women and children less than six years old. Over the years, the programme has been strengthened through added technologies such as fortification with iron (10 mg/litre), zinc (5 mg/litre), copper (0.5 mg/litre) and vitamin C (70 mg/litre). In 2003, the programme was reaching over 872 000

beneficiaries annually with 18 000 tonnes of food at a cost of US$38 million per year (Ruz *et al.*, 2005). Two small studies examined the consumption of fortified milk in association with mineral absorption and status. A cross-sectional study of 34 male children was carried out in an urban slum area. The children, aged 18 months, had all been exposed to the fortified-milk programme for at least six months. In this sample, the prevalence of anaemia was 12 percent, low iron stores (ferritin less than 10 µg/dl) was 39 percent and low plasma zinc (less than 12.3 µM/litre) was 54.8 percent. The investigators suggested programme exposure was associated with improved iron status compared with national averages (e.g. anaemia prevalence of 30–40 percent) but not improved zinc status (Torrejon *et al.*, 2004). Unfortunately, the study, assigned adequacy ranking, was not designed to draw inferences about the programme impacts.

The Mexican government has been operating a federal programme called Liconsa for many decades, selling subsidized milk to low-income households with children between one and 11 years old (Villalpando *et al.*, 2006). In 2000, the government began fortifying the subsidized milk with micronutrients (ferrous gluconate, zinc oxide and ascorbic acid) in an effort to address the problem of anaemia and iron deficiency among vulnerable groups. The initial research that led to this programme was a well-designed, double-blinded, RCT, which demonstrated the efficacy of fortified milk for reducing anaemia among infants (Villalpando *et al.*, 2006). The RCT, which achieved a probability ranking, was conducted in a poor, peri-urban region of Mexico to test the efficacy of the milk fortification. Children of 10–30 months old received a daily supplement of 400 ml of milk that was either fortified with iron, zinc and ascorbic acid (FM) or not fortified (NFM) for six months. The study found that the prevalence of anaemia in the FM group dropped from 41.4 percent to 12.1 percent but remained unchanged in the NFM group. Similarly, using logistic regression analysis, the study found that other iron biomarkers were positively affected in the FM group when age, gender and baseline status were controlled for ($P<0.001$). No differences in serum zinc concentrations were observed between the groups (Villalpando *et al.*, 2006). Nonetheless, due to its positive impacts on anaemia and iron status, the government of Mexico decided to scale up the use of fortified milk to reach 4.2 million children.

7.5.2 Asia and the Pacific

Milk fortification has proved effective for reducing morbidities in Asia. An RCT was carried out in India to study the effects of micronutrient fortified milk on morbidities caused by diarrhoea and acute respiratory illness (Sazawal *et al.*, 2007). Children aged 1–3 years received a daily supplement of either milk fortified with iron, zinc, selenium, copper and vitamins A, C and E or non-fortified milk and morbidity outcomes were followed weekly over a one-year period. The fortified milk was found to significantly reduce the odds of days with severe illness by 15 percent; incidence of diarrhoea by 18 percent and incidence of acute lower respiratory illness by 26 percent. Greater benefits were observed in the children less than 24 months old.

A large-scale observational study in Indonesia, ranked at the adequacy level of inference, demonstrated a positive association of consumption of fortified milk with reduced risk of anaemia among children of 6–59 months old (Semba *et al.*, 2010). Iron-fortified milk was associated with a 24 percent lower risk ($P<0.001$) of anaemia

in rural households and 21 percent lower risk ($P<0.001$) in urban households. This relationship was not observed in children receiving iron-fortified noodles, though an interaction effect was observed in children in rural households who consumed both fortified milk and noodles (Semba *et al.*, 2010).

7.5.3 Summary

Fewer evaluations were found for fortified-milk programme than for other programme types but the studies found involved well-designed trials that provided stronger evidence of the efficacy of milk fortification for improving nutrition. This is, in part, because testing for impact only requires the addition of the fortificant and no examination of other potentially complicated sets of interventions. Five fortified-milk programmes or studies were reviewed; two were classified as adequacy evaluations and three as probability evaluations. Metabolic studies show that nutrients can be absorbed from fortified milk, and community-based trials provide evidence that fortifying milk with iron and other micronutrients can improve iron status and reduce anaemia and other morbidities, especially among younger, undernourished children (Stekel *et al.*, 1988; Villalpando *et al.*, 2006; Sazawal *et al.*, 2007; Semba *et al.*, 2010). One study demonstrated improved vitamin D status in a group of children receiving milk fortified with cholecalciferol compared with the groups consuming milk fortified with only calcium (Du *et al.*, 2004), but the effect was not present after two years (Zhu *et al.*, 2006).

A notable finding of this evaluation is that results of studies of the efficacy of milk fortification are being more readily translated into policy and larger national programmes than those of other interventions. Ongoing challenges include limited market access and cost issues, and the need to determine whether zinc nutrition can be improved through milk fortification or other infant feeding strategies (Brown *et al.*, 2009).

7.6 MILK POWDER AND BLENDED FOODS

Milk powder has been added to other foods in many food-supplementation programmes over the years, but few have examined the separate impacts of the milk powder on nutrition outcomes. As milk powder also increases the costs of certain food products considerably, there is further need to understand its added value in terms of nutrition.

Hoppe *et al.* (2008) reviewed the evidence for use of whey and skimmed milk powder in fortified blended foods for young children and people living with HIV/AIDS. Bovine milk, they argue, is a good source of quality protein but stated that "there is no convincing evidence that whey has beneficial effects on antioxidant status, immunological parameters, or HIV-specific outcomes" and "there are no studies showing specific effects of [whey protein] in infants and young children in either well-nourished or malnourished populations" (Hoppe *et al.*, 2008).

A relatively new phenomenon in international nutrition programming is the use of a peanut-butter-based supplement first referred to as ready-to-use therapeutic (RUTF) or supplemental (RUSF) food. The food, depending on the organization or research group, may be referred to by different names such as lipid-based nutrient supplements (LNS) or milk-based fortified spreads. This food derives some of its nutritional value from the milk powder, with other ingredients usually including

peanuts, oil, sugar and micronutrient fortificants. In the following section, the evidence-base on the use of milk powder in blended foods is presented. In the programmes covered here, milk powder is added to other foods to enhance their nutritional value, rather than nutrients being added to milk to enrich its nutritional value (as was the case with fortified-milk programmes discussed in the previous section).

7.6.1 Latin America and the Caribbean

The Vaso de Leche Programme in Peru has been distributing milk, milk powder and cereals since the 1980s. A large-scale World Bank-funded evaluation, ranked at the plausibility level of inference, found that this large social transfer programme has delivered milk products to poor households with undernourished children but did not observe an association between public expenditures for this programme and anthropometric outcomes in demographic and health survey data from 1996 and 2000 (Stifel and Alderman, 2006). Milk powder is often included in commercially produced complementary foods in other parts of Latin America (Lutter *et al.*, 2008; Young Child Nutrition Working Group, 2009). Participatory recipe trials conducted in Haiti using USAID food aid products found that adding milk to corn–soy blend (CSB) increased both the energy and vitamin A content (Ruel *et al.*, 2004). This study, designated observational/formative, was not designed to demonstrate any effects on nutrition in young children.

7.6.2 Africa

The peanut-butter-based RUTF and RUSF products were first introduced by the company Nutriset, of Malaunay, France, as Plumpy'nut®. Plumpy'nut® is a mixture of peanut butter, milk powder, soybean oil, sugar and micronutrients. The paste is energy-dense (500 kcals per packet), resistant to bacterial contamination, easy to store, with a long shelf-life, and does not require cooking before feeding. There is a growing body of evidence of its effectiveness in community-based management of acute malnutrition, and some efforts are currently underway to investigate the effectiveness of similar products with different macro- and micronutrient compositions for preventing undernutrition. However, such interventions should generally be confined to countries with chronic emergencies or in crisis. Nutributter®, also produced by Nutriset and others, has been examined for efficacy in promoting growth, development and preventing micronutrient deficiencies (Adu-Afarwuah *et al.*, 2007). While dry, skimmed milk powder is currently a standard ingredient of these products, research is underway to test alternative products that do not include milk or have a reduced milk content, because of the high cost of milk powder.

The added nutritional value of the milk powder in the RUTF and RUSF has been examined to a limited extent. One randomized, controlled study in Malawi, ranked as probability level, compared three types of blended foods for improving recovery from moderate wasting (weight-for-height Z-score [WHZ] of greater than or equal to –3 but less than or equal to –2) (Matilsky *et al.*, 2009). In the first group, milk powder was added to a peanut paste that contained oil and sugar (25 percent milk, 26 percent peanut, 49 percent oil and sugar). The second group replaced the milk powder with soy powder (26 percent soy, 27 percent peanut, 47 percent oil and sugar). The third group was given CSB (80 percent corn, 20 percent soy). Important differences were found between the two food supplement

groups compared with the CSB group in terms of recovery from wasting, but not between the soy- and milk-supplemented groups. The rate of weight gain in the first two weeks was higher in the milk-supplemented group (2.6 g/kg per day) than in the soy-supplemented group (2.4 g/kg per day) and CSB group (2.0 g/kg per day), but statistically different only from the CSB group ($P<0.05$) (Matilsky *et al.*, 2009). No differences were detected in height-for-age Z-scores (HAZ) or length gain rates, although this is not unexpected since the study followed children only until they recovered from severe wasting (WHZ > –2) or for a total of eight weeks.

Another more recent study in Malawi did, however, demonstrate significantly higher recovery rates among severely, acutely malnourished children receiving RUTF with 25 percent of energy from milk powder compared with those receiving RUTF with 10 percent milk powder and added soy flour (Oakley *et al.*, 2010). This randomized, double-blind, controlled trial, ranked at probability level of inference, was conducted to assess the effectiveness of using locally produced food products with lower quantities of milk in an effort to lower production costs and expand availability of the food products.

Two studies in Niger also examined the effectiveness of milk-containing RUTF on nutrition outcomes, though neither one was designed to isolate the benefits conferred by the milk powder. The first applied a blanket targeting approach to prevent severe, acute malnourishment in children of 6–60 months old and with WHZ of greater than 80 percent of the National Center for Health Statistics median (Isanaka *et al.*, 2009). Using a cluster, randomized design, and thus receiving a plausibility ranking, six villages were assigned to be the intervention group (92 g of RUTF providing 500 kcal/day for three months) and six villages as the control. Children were followed monthly for seven months. In a time-to-event analysis with adjusted hazard ratios, the RUTF group showed 36 percent lower wasting incidence ($P<0.001$) and 53 percent lower incidence of severe wasting ($P<0.001$) (Isanaka *et al.*, 2009). No differences were found for stunting, morbidity or mortality, possibly because of the short follow-up period. In Maradi, Niger, blanket distribution of an RUSF to approximately 60 000 children of 6–36 months old during the "hunger gap" in 2007 reduced prevalence and incidence of severe acute malnutrition (mid-upper arm circumference less than 110 mm) during the hunger season (Defourny *et al.*, 2009).

A well-designed study in Ghana, receiving a probability ranking, demonstrated that children supplemented with Nutributter® from six to 12 months old were significantly heavier (WAZ) and taller (HAZ) than those supplemented with Sprinkles powder or crushable Nutritabs (Adu-Afarwuah *et al.*, 2007), and had significantly reduced iron deficiency anaemia than the unsupplemented control group (Adu-Afarwuah *et al.*, 2008). Nutributter® was the only supplement containing milk powder, but the study was not designed to isolate the effects of individual ingredients.

7.6.3 Summary

Milk enhances the nutritional value of blended foods, providing high-quality protein, fats and essential nutrients such as calcium, phosphorus, magnesium and vitamin A. The inclusion of milk in complementary foods, in particular, may be beneficial for growth for young children (Young Child Nutrition Working Group, 2009). Seven milk-powder and blended-food programmes or studies were reviewed;

one was classified as observational/formative level studies, one as adequacy level, two as plausibility level and three as probability level. The available evidence, however, does not allow conclusions to be drawn about the added value of the milk in the foods for achieving positive nutrition outcomes. Only one study in Malawi provided evidence that increasing the proportions of milk powder (from 10 percent to 25 percent) increased rates of recovery from severe acute malnutrition and weight and height gains (Oakley *et al.*, 2010). Programme evaluations and studies of RUTF and RUSF with relatively strong designs and methods have demonstrated that milk powder added to blended foods improved recovery rates and weight gain among malnourished children (Matilsky *et al.*, 2009), prevented wasting (Isanaka *et al.*, 2009; Defourny *et al.*, 2009) and promoted growth, motor development and micronutrient nutrition (Adu-Afarwuah *et al.*, 2007; Adu-Afarwuah *et al.*, 2008).

One important challenge for this programme type is cost. Milk powder added in even small percentages (10–15 percent) has been shown to double the cost of the food. Further, the shelf-life of a food may be shortened depending on the kind of milk powder added. Skimmed-milk powder may be a more practical alternative to whole-milk powder because of its longer shelf life (Hoppe *et al.*, 2008). For these reasons, more studies are needed to understand the added value of milk in blended foods for achieving positive nutrition outcomes.

7.7 KEY MESSAGES

Milk and dairy programmes hold promise for improving human nutrition. Micronutrient deficiencies arising from poor-quality diets and infectious disease remain widely prevalent in poor populations. Milk, as an ASF, is an efficient vehicle for delivering several critical micronutrients and improving growth of young children.

Evidence from well-designed evaluations and studies of milk programming remains limited. Of the 29 evaluations and studies reviewed, only six met the probability level of inference, i.e. were able to demonstrate a causal link between a milk intervention and nutrition outcome, and eight met the plausibility level with quasi-experimental designs. Clearly, there is a need for better-designed process and impact evaluations, cost-effectiveness analyses and careful consideration of the dual burden of under- and overnutrition.

Lessons learned from dairy production and agriculture programmes show the importance of multisectoral interventions targeting women and strategies introducing small livestock species and improved breeds, establishing market linkages and increasing awareness about the nutritional importance of milk. Nutrition objectives are needed more generally in dairy production and agriculture programmes. School-based milk programmes have demonstrated positive impacts on growth, body composition and micronutrient status, but the issue of appropriate levels of fat and added sugar and flavouring in milk need to be addressed. Evidence of efficacy is strongest for fortified-milk programming, showing improvements in iron and vitamin D nutrition in particular. Issues of limited market access, cost and questionable effects on zinc nutrition remain. Milk added to blended foods has been used in programming for decades, but the isolated effect of the milk ingredient is largely unknown.

In conclusion, milk and dairy programming offers many opportunities moving forward. Animal milk, rich in bio-available nutrients, delivered to young children

may prevent micronutrient deficiencies and stunted growth. Evidence also shows that milk programming can stimulate local production and simultaneously address malnutrition and poverty. Finally, the prevailing positive public perception of the nutritional advantages of milk in some contexts such as pastoralist and school communities offers fertile grounds for programming. With future investment and careful planning, milk programming can make an important contribution to improving nutrition and development around the world.

DISCLOSURE STATEMENT

The author declares that no financial or other conflict of interest exists in relation to the content of the chapter.

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ANNEX

TABLE 7.1

Milk programmes and studies affecting nutrition

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
	Dairy production and agriculture programmes					
AFRICA	Ethiopia/FARM Africa Dairy Goat Development Project (1988–1995) Gursum study (1998–2001) Ayele and Peacock (2003)	Households & children 6 mo–6 y	Improve family welfare through increased income and milk consumption	Goats provided to poor, female-headed household (HH) Credit and saving groups organized Matched savings for further investments Extension support for animal health	Pre- (Nov. 2000) and post- (Nov. 2001) intervention design, with some process indicators also collected Case studies conducted in two programme districts HKI food frequency method used to measure consumption	*Adequacy* Frequency of milk consumed by children (d/wk) increased Availability of milk increased from pre- to post-intervention (Gorogutu District) Household used milk for home consumption, especially for small children (Gursum District) Increased availability of other foods such as meat, eggs, and vegetables
AFRICA	Ethiopia/FARM Africa Dairy Goat Development Project plus new intervention (1995–1998) Ayalew, Gebriel and Kassa (1999)	Households & children < 5 yr	Improve vitamin A status of participating households by adding an integrated package promoting nutrition messages to the DGDP	*Nutrition messaging to women's groups to increase knowledge added to DGDP project above *Skills training in production of vitamin-A rich foods and feeding practices	Endline comparison (Jan–March 1998) of participants (n=214) and non-participants (n=106) Qualitative and quantitative data collected	*Adequacy* Nutritional awareness increased in participating household Vegetable and fruit gardening increased in participating household Goat-owning households consume more milk than non-goat owning households Prevalence of Bitot spots lower in participant group; no difference in night blindness

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
AFRICA	Ethiopia/Ethiopian Agricultural Research Organization & International Livestock Research Institute (ILRI) Dairy technology project (1995–1996) Ahmed, Jabbar and Ehui (2000)	Farm households	Improve household income and nutrition	*Cross-bred cows were introduced for milk production and traction *Feeding and dairy management technologies introduced	A longitudinal design was used to collect data monthly from 84 households in 1997 Group 1: participating households with cross-bred cows Group 2: control group using traditional practices matched by wealth groups Total n=84	*Plausibility* *Increase in household income associated with dairy technologies ($P<0.001$) *Income increases related to higher food expenditures ($P<0.001$) *Cross-bred cows and technologies related to increased per capita household energy intake ($P<0.001$)
	Ethiopia/Save The Children Role and value of milk among pastoralists Sadler and Catley (2009)	Pastoralist men and women	Describe pastoralists impressions on causes of child malnutrition, links between nutrition and milk supply, and interventions to address malnutrition	Not relevant	Participatory methods applied including: matrix scoring; seasonal calendars; and ranking Pastoralist women of mixed wealth group (n=8–12); pastoralist men (n=4–10) from four locations in Somali Region	*Observational / Formative* *Perceived benefit and awareness of nutritional value of livestock milk, especially among women *Demand high for milk to feed young children *Milk provides 2/3's of energy, and 100% of protein needs of young children *Season and drought reduce milk supply *Improve animal health (fodder, water, and veterinary care) as intervention to sustain availability of milk for children

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
AFRICA	Kenya/Government of Kenya National Dairy Development Project (NDDP) (1980–1995) Hoorweg, Leegwater and Veerman (2000)	Households 6–59 m	Improve dairy management on mixed smallholder farms practices through zero-grazing	▪ Extension services provided to promote zero-grazing practices ▪ Veterinary services ▪ Assistance to participants to obtain loans for start-up capital	Cross-sectional study from May–June 1987. Dietary intakes measured with 24-hr recall, and anthropometry measured for children 6–59 mo. DDP farmers started before 1980 (n=30); dairy customers of DDP-farmers (n=24); and rural farming households in in same agro-ecological zones of dairy farmers (n=90)	*Plausibility* *Frequency and quantity of milk consumed increased in DDP and customer groups *HAZ and WAZ higher in DDP and customer groups *Energy intakes highest in dairy groups
	Kenya/Government of Kenya National Dairy Development Project (NDDP) (1980–1995) Mullins and Wahome (1996)	Households	See above Study conducted to examine differences in dairy farming benefits based on male or female extension agent	See above	Quantitative and qualitative methods in cross-sectional study in February 1993 Households stratified by male or female extension contacts (n=32)	*Observational / Formative* *On male contact farmers, 3/4's of dairy operators are women *Only on female contact farms did dairy income accrue to women *consensus that intensive dairying has led to improved income and milk consumption *Women on female contact farms spend more dairy income on school and food for households than HH of male contact farms

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
AFRICA	Kenya and Ethiopia/ILRI Market-oriented smallholder dairying (MOSD) Tangka, Ouma and Staal (1999)	Households	Explore consequences of MOSD on women's wellbeing in East Africa	Kenya – non-project ownership of cross-bred cows in 1996 Ethiopia – project to develop technologies for poor farmers to participate in MOSD	Cross-sectional household studies carried out in Kenya and Ethiopia in 1996 Kenya – 260 household with cross-bred cows in Kiambu Ethioipia – 120 households with cross-bred and local cows	*Observational / Formative* *Large proportion of dairy operators (70% in Kenya) were women *MOSD in Kenya increased women's labour and income; these effects on women smaller in Ethiopia *Women will benefit more from MOSD with increased access to inputs (land, fodder, credit, etc.)
ASIA AND PACIFIC	Bangladesh Cambodia Nepal: IFPRI/Helen Keller International Homestead food production Iannotti, Cunningham and Ruel (2009)	Mothers and children less than 5 years of age	Improve production of micronutrient-rich foods; increase income; empower women; and improve nutritional status	*HKI partners with local NGOs to promote home gardening and small livestock development *Village model farms (VMF) established *VMF serve as source of production inputs and nutrition education	Evaluations, generally cross-sectional studies some pre- and post-intervention and some post-intervention with intervention and comparison groups, carried out from 1981 to the present Review of Bangladesh, Cambodia HKI programme evaluations	*Adequacy* *Increased food availability (developed gardens) *Increased food access (food expenditures from HFP income) *Increased dietary diversity and consumption of micronutrient-rich foods including milk

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
ASIA AND PACIFIC	India: IFPRI/ Government of India Operation Flood (1970–1996) Cunningham (2009)	Smallholder farmers	Increase milk production, stable supply, and increase incomes of small farmers	*Created a "national milk grid" or a dairy-supply chain from village to district to state *Producer cooperatives established to: collect milk; ensure quality; provide payment; improve management techniques; and provide access to veterinary services *Food aid milk powder and butter oil used for processing during slack seasons in domestic production	Pre- and post-assessment of trends in milk production, consumption, and several of service delivery outcomes District (Bikaner, Periyar, and Sabarkantha) and nationally representative data	*Adequacy* *Per capita milk consumption from 290 to 339 g/d between 1988–89 to 1995–96 *World's largest producer of buffalo and goat milk; 6th largest producer of cow milk *Dairy production role 4.5%/yr over 30 years *Favourable effects on income distribution and women's employment *Linked dairy producers to urban consumers *Technological advances in cross-breed raising and milk processing
	India/IFPRI Karnataka Dairy Development Project Alderman (1987)	Smallholder farmers	Modelled after *Operation Flood*, aimed to increase milk production through improved animal nutrition and cross-breeding	*Introduce cooperatives to commercialise dairy products *Raise producer prices	Longitudinal study with 5 rounds of household surveys between Jan 1983 to April 1984; multivariate regression analyses conducted Intervention group: non-random selection of 21 villages with cooperatives Control group: non-random selection of 10 villages without (total HH n=806)	*Plausibility* *Twice as much milk produced in intervention group than control attributed to larger number of cross-bred cows and buffalo *Price increases in rice and ragi reduced calorie and protein consumption, but price increases in milk, did not ($P<0.05$) *Nutrient consumption among producers increased due to income increases *Cooperatives increased incomes of producers

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
ASIA AND PACIFIC	Viet Nam/Ministry of Health in Viet Nam VAC Farming System Hop (2003)	Women Children < 5 years	Provide diversified agricultural products to meet complex nutritional demands of population	*Ecosystem approach to protecting livelihoods, health and environment *Land distribution and development by government *VACVINA loans for poor *Environmental protection	National level data on ASF production and consumption, and nutritional status reviewed. Ecological analysis only. National Nutrition Surveys in 1999 and 2000 compared, because VAC was a national programme	*Observational / Formative* *Percentage of protein and fat in the diet increased *Underweight in children < 5 yr decreased from 51.5% in 1985 to 31.9% in 2001 *Stunting in children < 5 yr decreased from 59.7% in 1985 to 34.8% in 2001 *Anaemia prevalence decreased among children < 5 yr and women of reproductive age
	School-based milk programmes					
AFRICA	Kenya Study: Meat and milk supplementation in schools (Aug 1998–July 2000) Neumann *et al.* (2007) Grillenberger *et al.* (2003)	6–14 yrs (median 7.4 yr)	Investigate effect of animal source food (meat and milk) groups on growth, cognition, and physical activity	*School-based mid-morning snack daily over 2.5 years (total 23 mo) *Githeri, a local dish with maize, beans, and greens, provided with meat, milk, or oil in 3 intervention groups	Longitudinal study in 12 schools in Embu District, stratified by size and access to food delivery Group 1: githeri + meat Group 2: githeri + milk Group 3: githeri + oil Group 4: control Total (n=544)	*Plausibility* *Among stunted children at baseline, milk group children gained 1.3 cm more height (15%) than control (P=0.05) *Groups 1–3 showed greater weight gain (~10%) than Group 4 control; effect greater in boys, younger children, and lower SES *Group 1 (meat) followed by group 2 (milk) showed greatest increase in mid-arm muscle area compared to other groups *Group 2 (milk) showed lowest rate of Raven's Progressive Matrice (RPM) compared to all groups

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
ASIA AND PACIFIC	China Milk supplementation trial (April 1999–March 2001) Du *et al.* (2004) Zhu *et al.* (2006)	Girls 10 yrs	Investigate the effect of milk supplementation in pre-pubertal children on growth and bone health; test whether vitamin D fortification would improve vitamin D status	Daily milk supplementation provided to girls in primary schools for two years *Nine primary schools matched and randomised	Longitudinal, cluster randomised study for intervention efficacy after 3 yr Follow-up longitudinal study after another 3 years after trial in 501 of 698 girls Group 1 – 330 ml of milk fortified with Ca (n=238) Group 2 – 330 ml of milk fortified with cholecalciferol (n=260) Group 3 – control (n=259) Groups 1 & 2 received milk daily for 2 years during the school days	*Plausibility* *Both milk groups showed significant increases in height (≥0.6%); sitting height (≥0.8%), body weight (≥2.9 %), size-adjusted total body bone mineral content (≥1.2%); and bone mineral density (≥3.2%) compared to control (group 3) *Group 2 with cholecalciferol showed significant changes in bone mineral content and bone mineral density; and improved vitamin D status compared to Group 1, milk without cholecalciferol *Follow-up study found no significant differences in total bone-mineral content or density *Follow-up study showed greater gains in sitting height (0.9±0.3%; *P*=0.02)
	Mongolia/Government of Mongolia School milk and nutrition in Gobi Desert (2006–present) CFC, APHCAP and FAO (2008)	5–10 yrs Primary school children	Improve nutrition of children vulnerable to undernutrition and micronutrient deficiencies	*Students receive 200 ml of milk daily *Public–private partnership that supports only domestically produced milk and milk products *Linked to Mongolia milk advertising and education campaign	Dairy food security project study assessed only coverage and market linkages	*Adequacy* *200 000 children reached

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
ASIA AND PACIFIC	Thailand/Royal Thai Government National School Milk Programme (1983–present) Smitasiri and Chotiboriboon (2003)	Pre- and primary school children	Increase domestic smallholder production and milk consumption	*National Milk Drinking Campaign Board established in 1985; free school milk programme and school milk corners *200 mL/child/d for 200 d/y since 1992 to all government-supported preschool centres and to underweight children in public primary schools (Kindergarten–Grade 4)	Nationwide survey with qualitative and quantitative methods by Institute of Nutrition, Mahidol University (INMU) A second study by Kasetart University compared health and motor fitness of schoolchildren in Bangkok in milk programme schools compared to non-milk programme schools Group1: students in programme schools Group 2: students non-programme schools	*Adequacy* INMU study *6 million pre- and primary school children receive milk 230 days per year *Milk consumption increased from 2 litres per capita in 1984 to 23 in 2002 *Energy, protein, calcium, and vitamin B_{12} intakes above usual diets; suggested impact on height Kasetart University study *Students in programme-schools taller than students in non-programme schools; no difference in motor fitness
	Viet Nam/Land of Lakes School nutrition programme (2003–2005) Hall *et al.* (2007)	Primary school children	Improve weight gain and growth in Vietnamese school children	*Large-scale programme supported by USDA commodities in 2075 schools in six provinces of Viet Nam. *For evaluation, intervention group received 30 g wheat flour biscuit (150 kcal) and 200 ml of UHT milk fortified with vitamins A and D (150 kcal) daily during the school period as a snack	Cluster evaluation carried out in one of the programme provinces, Dong Thap in 21 schools Cohort study of 1080 children in grade 1, and cross-sectional study of 400 children in grade 3 Group1: students in programme schools (n=360) Group 2: students non-programme schools (n=720)	*Plausibility* *Significant differences found for intervention group compared to control in height gain 8.15 cm vs. 7.88 cm, and weight gain 3.19 kg vs. 2.95 kg, respectively *Programme effect on weight but not height upheld after adjusting for other variables *No substitution effects found

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
ASIA AND PACIFIC	Iran CFC, APHCAP and FAO (2008)	Primary school-age children	Prevent poor nutrition (growth) and health outcomes (osteoporosis); long-term goal to promote sustainable dairy industry development	*3 portions (20 cl) milk per week; total of 70 per 6 mo *Tetra Pak public–private partnership	Performance measurement study conducted for coverage and milk production outcomes	*Adequacy* *12 million students now receiving milk; increase of 400% from original 1.2 million *7% increase in milk production, 187.5 million litres
	Fortified milk programmes					
LATIN AMERICA AND THE CARIBBEAN	Chile/University of Chile Prevention of iron deficiency through milk fortification (1986–1987) Stekel *et al.* (1988)	3–15 mo partially or fully weaned	Determine effectiveness of fortified milk on prevention of iron deficiency and anaemia	*Fortified (intervention) and non-fortified full-fat milk in a 10% dilution (st/vol) plus 5% sucrose, and 3% corn flour given to infants daily from 3 to 15 mo	Longitudinal study, randomised controlled study conducted in two clinics in Santiago, Chile Intervention group: full-fat fortified milk powder with 15 mg ferrous sulphate, 100 mg ascorbic acid, 1 500 IU vitamin A, and 400 IU vitamin D per 100 g (n=276) Control group: non-fortified, full-fat milk (n=278)	*Probability* *Reduced anaemia prevalence in intervention group (2.5%) vs control group (25.7%) at 15 mo (P<0.001) *Low transferrin saturation was reduced in intervention (7%) compared to control (33.8%) *Low serum ferritin reduced in intervention (8.5%) compared to control (39%)

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
LATIN AMERICA AND THE CARIBBEAN	Chile/University of Chile National Complementary Food Program of Chile (1999–present) Torrejon *et al.* (2004)	18 mo	Prevent mineral deficiencies by fortifying milk	*Fortified milk given through the National Complementary Food Programme for at least 6 mo *Milk fortified with iron (10mg/L), zinc (5 mg/L), copper (0.5 mg/L) and vitamin C (70 mg/L) *Original programme, began in 1920s, supplemented pregnant women and children under six years with milk	Cross-sectional study of low-income male infants attending well-baby clinic and participating in national programme Nutrition survey and biomarkers collected and analysed Intervention group only	*Adequacy* *At endline only, prevalence of anaemia (12%); low ferritin < 10μg/dL (39%); and low plasma zinc <12.3 μM/L (54.3%) *Hb 12.1±1 (10.7–14.0); ferritin 9.6 μg/dL (4.4–21.3); plasma zinc 12.7±1.9 μM/L (8.4–18.4)
	Mexico/Instituto Nacional de Salud Publica Fortified milk in LICONSA (2000–present) Villalpando *et al.* (2006)	10–30 mo	Assess efficacy of whole cow's milk fortified with iron and zinc on reducing anaemia and improving iron status of low-income children	*Ferrous gluconate added to cow's milk with ascorbic acid as part of LICONSA public nutrition programme *Intervention group receive 400 mL/d of fortified milk with 5.8 mg iron (ferrous gluconate), 5.28 zinc (zinc oxide), 48 mg ascorbic acid for six months *Control group received 400 ml/d non-fortified milk *Field worker visit household 2 times/d to ensure correct reconstitution of milk and record milk intake	Randomised, double blinded controlled trial in poor periurban area of Mexico Group 1: healthy children drink 400 mL/d of fortified milk (n=68) Group 2: healthy children drink 400 ml/d non-fortified milk (n=62)	*Probability* *Anaemia prevalence significantly reduced from 41.4% to 12.1% (P<0.001) in group 1; no change in group 2 *Haemoglobin concentration was positively and serum transferrin receptor (sTFR) was negatively associated with treatment (P<0.001) *No differences in serum zinc concentrations between groups observed *Study led to scaling up of fortified milk programme to 4.2 million children

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
ASIA AND PACIFIC	India/Center for Micronutrient Research in India/Johns Hopkins Bloomberg School of Public Health Efficacy of fortified milk on morbidity (2002–2004) Sazawal *et al.* (2007)	1–3 yrs	Evaluate efficacy of micronutrient fortified milk on morbidity outcomes (diarrhoea, acute respiratory illness)	Intervention group: fortified milk with iron (9.6 mg), zinc (7.8 mg), selenium (4.2 µg), copper (0.27 mg), vit A (156 µg), vit C (40.2 mg), and vit E (7.5 mg)	Randomised, double-blinded controlled trial in peri-urban region of northern India Intervention group: fortified milk for one year (n=316) Control group: non-fortified milk for one year (n=317)	*Probability* *Odds of days with severe illness reduced by 15%, incidence of diarrhoea by 18%, and incidence of acute lower respiratory illness by 26% *Greater benefits observed in younger children (≤24 mo)
	Indonesia/Johns Hopkins University Consumption of iron-fortified milk and noodles (1999–2003) Semba *et al.* (2010)	6–59 mo	Determine the level of risk reduction for anaemia associated with consumption of iron-fortified milk and noodles	*Families participating in Nutritional Surveillance System (NSS) of Ministry of Health and Helen Keller International *Child consumption of milk or noodles in the previous week and commercial brand of product documented *HemoCue used to measure haemoglobin in children	Observational study using stratified, multistage cluster sampling to collect survey data over 17 rounds; multiple logistic regression models used to examine determinants (fortified milk and noodles) of child anaemia 4 800 urban households and 1 560 rural households	*Plausibility* *Children showed significantly lower risk of anaemia associated with consumption of fortified milk in both rural and urban areas, adjusted OR: 0.76; 95% CI: 0.72, 0.80 (P<0.0001) and adjusted OR: 0.79; 95% CI: 0.74, 0.86 (P<0.0001), respectively *No association found for consumption of fortified noodles, though in rural families, interaction demonstrated for consumption of both fortified milk and noodles

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
	Milk powder and blended foods					
AFRICA	Ghana/University of Ghana/University of CA-Davis Home fortification of complementary foods (February 2004–June 2005) Adu-Afarwuah *et al.* (2007) Adu-Afarwuah *et al.* (2008)	6 mo	Compare the impact of different types of micronutrient supplements added to home-prepared CF on growth, micronutrient status, and development outcomes	*Infants randomised to receive one of 3 home fortification methods or into control group *Daily dose from 6 to 12 mo *Infants followed weekly for dietary intake and morbidity outcomes *Anthropometry collected at 6, 9, and 12 mo; biomarkers at 6 and 12 mo; motor development at 12 mo	Randomised, controlled trial in Koforidua of Ghana; all infants followed longitudinally at 6, 9, and 12 mo Group 1: Sprinkles Group 2: Nutritab Group 3: Nutributter with dry skimmed milk Group 4: control Total (n=313)	*Probability* *Nutributter group had greater WAZ and HAZ than Nutritab and Sprinkles group (P=0.05); no significance difference with control group *Nutributter group showed higher percentage of children walking independently by 12 mo *3 intervention groups showed higher ferritin and lower transferring receptor concentrations than control at 12 mo *Iron deficiency anaemia lower (10%) in interventions groups compared to control (31%) (P<0.0001)
	Malawi/Washington University/FANTA Supplemental feeding with fortified spreads[1] (January 2007–February 2008) Matilsky *et al.* (2009)	6–60 m WHZ between –3 and –2	Investigate whether fortified spreads (FS) (milk and soy) improve recovery rates from moderate wasting compared to corn soy blend (CSB) food aid product	*Children randomised to receive one of three food products daily until exceeded target weight (.1 kg > WHZ) or until 8 weeks *Assessed every 2 weeks	Randomised, clinical effectiveness trial. Children followed biweekly for 8 weeks Group 1: milk powder peanut FS (25% milk; 26% peanut; 49% oil & sugar) Group 2: soy powder peanut FS (26% soy; 27% peanut; 47% oil & sugar) Group 3: corn soy blend (80% corn; 20% soy)	*Probability* *Higher percentages of children in the milk and soy FS groups recovered from wasting than the corn soy blend (80% for groups 1&2; 72% for group 3; P<0.01) *Rate of weight gain in first 2 wk higher in milk FS group (2.6 g/kg/d) and soy FS group (2.4 g/kg/d) compared to CSB group (2.0 g/kg/d)(P<0.05) *No differences is length gain rates

[1] Fortified spread here refers to ready to use therapeutic food (RUTF).

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
AFRICA	Malawi/Washington University Supplemental feeding with fortified spreads (January 2007–February 2008) Oakley *et al.* (2010)	6–59 mo	Test the effectiveness of a lower milk content RUTF on recovery from severe acute malnutrition	*Severely malnourished (WHZ<–3 and/or bipedal pitting oedema) children from 15 rural areas included *RUTF food products, locally produced, given to children as home-based therapy *2 groups receive RUTF given in same isoenergetic quantities 733 kJ/kg/d or 175 kcal/kg/d *Group 1 product include 25% energy from milk powder; and group 2 with 10% milk and soy flour	Randomised, double-blind, controlled, effectiveness trial Assessed every 2 weeks Group 1: RUTF with 25% of milk Group 2: RUTF with 10% of milk (n=1 874)	*Probability* *Recovery from severe acute malnutrition greater in group 1 with higher milk content at both 4 wk and 8 wk (P<0.001) *Weight and height gain rates higher in group 1 with higher milk content
	Niger/Harvard School of Public Health Effect of Preventive Supplementation with RUTF (August 2006 to March 2007) Isanaka *et al.* (2009)	6–60 mo WHZ <80% of National Center for Health Statistics median	Test the effectiveness of RUTF on nutrition, morbidity and mortality	*Monthly supply of RUTF as Plumpy'nut® given to households *Caregivers instructed to give 92 g/d sachets to children *Children followed monthly for nutrition, morbidity, and mortality outcomes	Cluster, randomised trial of 12 villages. Children followed monthly for 7 months Intervention group: 92 g/d of RUTF (500 kcal/d) for 3 months Control group Total (n=3 533)	*Plausibility* *Adjusted effect of RUTF intervention was a 0.22 increase in WHZ (95% CI: 0.13–0.30) *Intervention reduced any wasting incidence by 36% (P<0.001) and severe wasting by 53% (P<0.001), adjusted hazard ratios *No differences in stunting, morbidities or mortality

TABLE 7.1 *(continued)*

	Country/organization Title (duration) Reference	Target population	Goal/ objective	Intervention: strategy and activities	Design: comparison groups and methods	*Level of Inference* Results
AFRICA	Niger/Ministry of Health & Medicins Sans Frontiers Large-scale distribution of milk-based fortified spreads (2007) Defourny *et al.* (2009)	6–36 mo	Evaluate strategy to prevent seasonal rise in severe acute malnutrition	*Monthly distribution of Plumpy'Doz® from May to October 2007 *Caregivers instructed to give 3 tablespoons (250 kcal/d) to each child per day *Admission to the MSF therapeutic feeding programme and mid-upper arm circumference (MUAC) was tracked	Ecological assessment comparing programme period wasting incidence to previous years No groups. All children in Maradi 6–36 mo (n=60 000)	*Adequacy* *Incidence of severe acute malnutrition (MUAC<110 mm) remained low during hunger season *Blanket distribution showed same flattening effect as individualised treatment of moderately malnourished children
LATIN AMERICA AND THE CARIBBEAN	Haiti: Cornell University/ IFPRI Study: Participatory recipe trials of CSB and WSB ref Ruel *et al.* (2004)	6–23 mo	Assess whether fortified cereal blends complemented with locally available foods (including milk powder) can improve the nutrient density of CF foods	*Conduct participatory trials of complementary foods *Foods prepared and tested for acceptability, feasibility, and affordability *Develop new recipes with local ingredients	Participatory recipe trials conducted in 11 communities of Central Plateau No groups	*Observational / Formative* *Feasible to improve nutrient density of complementary foods in rural Haiti *Milk powder added to CSB improves energy and vitamin A content
	Peru/Government of Peru Vaso de Leche "Glass of Milk" (1984–present) Stifel and Alderman (2006)	Households with children <6 yr, pregnant or lactating women	In-kind social transfer programme to improve nutrition in vulnerable populations	*Pilot in 1984; expanded late 1980s and by 1998, 44% of households with children 3–11 yrs reached *Milk, milk powder, cereals, or combination of commodities distributed *Priority given to households with children < 6 yrs, pregnant and lactating mothers	Econometric analysis of public expenditure data (1994–2000), Living Standard Surveys (1994, 1997, 2000), and DHS data (1996, 2000) used to examine programme coverage and model determinants of nutrition Intent-to-treat analysis comparing groups eligible population where treatment is available to similar population (counterfactual) where no programme is available (n=28 000+ households)	*Plausibility* *Vaso de Leche targets vulnerable groups; in-kind or conditional transfer reached poor households with low nutritional status (50% of poor HH vs. 20% of non-poor) *Milk accounts for 93.3% of value of transfers for 2 poorest quintiles; milk powder for 80.4% *No difference in anthropometry of children less than five years observed between comparison groups

Chapter 8

Dairy-industry development programmes: Their role in food and nutrition security and poverty reduction

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ABSTRACT

This chapter focuses on dairy-industry development programmes (DIDPs) in developing countries where nearly one billion people live on dairy farms, smallholdings or in landless households keeping one or more animals. It differs from other chapters in this publication in that it is generated from knowledge-based or field-learned experiences, with some non-academic sources. The chapter focuses on selected programmes and projects with objectives including nutrition and women's empowerment through dairying, and enterprise-oriented dairy development to improve the livelihoods of poor families at scale. It highlights the pivotal role of milk and dairy products in the diet of peoples in many parts of the developing world, and how DIDPs have leveraged milk's unique functional properties, contributing both to household food security and to improving rural livelihoods for millions of small-scale dairy farming families through generation of regular income and employment along the dairy value chain. Experience indicates that investments in national capacity and local dairy organizations and institutions can facilitate smallholder participation in DIDPs. They can also significantly enhance household food security, and pay both economically and socially. There are particular benefits to women, often the decision-makers for household food and nutrition choices. High importance is attached to modest but regular cash incomes from dairying. Investment risks in dairying must be well managed, but there appear to be compelling opportunities to drive the expansion and upscaling of DIDPs in many developing countries. The authors argue that design of the dairy-industry value chain must benefit from FAO's unique comparative advantage in leveraging know-how and investment from public and private sectors. There are, however, challenges for public and private sector partners to ensure that smallholders and their enterprises benefit from dairy-industry development and to ensure that nutritional outcomes are included as DIDP objectives.

Keywords: Dairy industry, inclusive dairy value chain development, SME investments, improved dairy-industry programme design, women benefits dairying, income, employment

8.1 INTRODUCTION

This chapter reviews diverse dairy programmes and provides insights on maximizing the benefits of dairying for smallholders. In developing countries, smallholders play an important part in providing milk and milk products; with demand increasing, they can also have a more significant role in dairy-industry development. We define dairy-industry development as activities that ensure milk and dairy products are available, affordable, nutritious and safe by assisting small- and medium-scale dairy producers, processors and service providers to maximize their capacities to meet demand.

In developing countries, dairy farmers range on a continuum from subsistence activities outside the cash economy, through more commercial/industrialized production in the formal cash economy, to specialized peri-urban pockets of dairying resembling highly-capitalized production in developed countries (World Bank, 2007a). FAO (2008) describes this evolution from subsistence smallholder milk producer to small-scale commercial dairy farmer process as a virtuous circle. Rising earnings from dairying foster indigenous expertise and manufacturing in off-farm jobs, which compete with dairying for labour but also boost demand for dairy products (Candler and Kumar, 1998). Smallholder production stimulates rural development in both developing and developed countries by creating on-farm employment and income opportunities beyond the farm gate, e.g. in Ghana one full-time job is created for every 20 litres of milk collected, processed and marketed (FAO, 2004a).The more this formalization of smallholder dairying proceeds the more it can be termed industrial.

While there has been significant interest in dairy-industry development over the last 50–60 years, not all efforts were sustainable. Some early DIDPs were supply driven rather than demand or nutrition driven. In Africa the model was often for international and especially bilateral agencies to transfer large-scale Western technologies mainly from the dairy plant to the consumer. These often failed.

Significantly, home-bred programmes in South Africa and Zimbabwe had specifically excluded smallholder local farmers through rules and regulations that favoured larger farms. In contrast, Kenya is a good example of inclusion of smallholders in the dairy industry. In South Asia, especially Bangladesh and India, recent DIDPs focus on very poor, even landless, farmers with pro-poor partners such as Grameen Bank; as a result they are well tailored to local conditions.

Milk is a source of regular income, because it is produced and sold daily and cannot be stored like arable crops. In developing countries dairy animals are kept by small-scale farmers, mainly in mixed-farming operations. In addition to meat, milk, hides and traction for carts and ploughs, animals provide income, employment, sociocultural wealth and act as cash reserves. In some systems dairy animals are fed crop residues and their wastes furnish fuel for energy and organic fertilizer. Manure for fuel is fundamental in many countries, especially South Asia (Afghanistan, Bangladesh, India and Pakistan), and there is increasing interest in manure as a sustainable source of biogas in rural areas. In some farming systems manure

is critically important for increasing yields in crop agriculture (A. Rota, personal communication, 2012).

Demand for milk and dairy products has grown significantly in many Asian countries, partly because of population growth but also because people are spending more disposable income on livestock products. Demand for milk in developing countries is increasing fast: Delgado *et al.* (1999) estimated that milk consumption in the Asia–Pacific region would double to 231 billion litres of liquid milk equivalent (LME) by 2020, but it actually reached 240 billion litres LME by 2007 (see also Chapter 2). With such high projected demand there will be significant opportunities for small- and medium-scale producers. Regional imports from Australia, New Zealand and North America via brokers such as Fonterra may also increase by about 30 percent, but Asian–Pacific smallholders could meet as much as 70 percent of demand if there are improvements in market channels and the institutional set-up to ensure smallholders are included in the value chain. Thus, smallholders can improve their countries' trade balances, even before they export (FAO, 2009a). Large-scale global investment in dairying is also on the rise, fuelled by the high international price for milk commodities in recent years. Large-scale and intensive dairying can produce milk very efficiently but there are some environmental concerns regarding concentrated resource use and waste generation (see also Chapter 2).

Dairying in developing regions has been studied by FAO, the European Union (EU), the International Livestock Research Institute (ILRI), the United Nations Development Programme (UNDP), World Bank and bilateral donors for decades. A World Bank study concluded that most countries in sub-Saharan Africa (accounting for about 75 percent of the region's population) could become self sufficient in milk (Walshe *et al.*, 1991). The *Strategy and Investment Plan for Smallholder Dairy Development in Asia* (2009–2018) (FAO, 2008) was developed through a participatory process involving public and private sectors in 18 countries, and focuses on increasing milk production and improving nutrition; the first objective of the ten-year, US$250 million investment plan is "a glass of Asian milk per day for every Asian child" (Dugdill and Morgan, 2008).

Dairy production systems vary across agro-ecological zones. Feed is the largest input and cost in most systems, more so when labour involved in producing the feed is factored in. In addition to grazing and fodder crops, feed rations are commonly augmented with crop residues and industrial by-products, such as molasses, wastes from breweries and flour mills, oilseed cake, fruit pulp and vegetable waste (Henriksen, 2009).

About 85 percent of smallholders milk cows. But people of different cultures milk other animals, ranging from larger animals (cattle, buffalos, yaks, camels, llamas, alpaca, horses, donkeys, reindeer) to small, less costly ruminants (goats, sheep). There is a dearth of peer-reviewed international literature on the role and contribution of other species in meeting the needs of a growing human population. Field observations from a number of partners in developing countries do, however, indicate that their impact on both household food security and poverty alleviation is very significant.

There are thousands of unique, nutritious, traditional dairy products around the developing world whose main function is to preserve milk surpluses for consumption in the winter or during the dry season. A few cultures use dairy products for cosmetics, e.g. in Eritrea (*likay* from cow's blood and milk) and Ethiopia (butter).

Elsewhere milk is sacred, e.g. Mongolia where it is sprinkled on horses' hooves and the wheels of vehicles before journeys. In India dairy cows are sacred. Milk animals are used for food production and draught purposes in Bangladesh, India and Pakistan.

Smallholder dairying is complex, requiring wide-ranging skills. Like other agricultural sectors, the dairy sector needs institutional support and guidance to contribute to national development, family well-being and nutrition, particularly in rural areas. The nature of the institutions is critically important for inclusion or exclusion of smallholder dairy farmers. Development of smallholder dairy farmers' organizations is often seen as the single most important institutional factor for development of the dairy sector where the smallholders are included.

Dairying helps to achieve the first Millennium Development Goal, the eradication of poverty and hunger (Box 8.1).

8.2 INCOME AND EMPLOYMENT GENERATION

Income and employment are key drivers of livelihood improvement in smallholder DIDPs. A number of organizations conclude that market-oriented small-scale dairying can increase household income, reduce food losses, generate employment in milk collection, processing and marketing and stimulate rural development (Bennett *et al*., 2006; FAO, 2005a). There are many approaches and models adapted to local environments, and these are described in Section 8.7.

Many governments have invested in DIDPs. The largest example is India's Operation Flood, replicated in selected states with the technical support of FAO from 1970 to 1996. It was successful both because it was driven by demand created by urban milk droughts, and because bottom-up cooperative milk products were actively marketed, even advertised in topical cartoons, attracting consumers. Record quantities of dairy products supplied from European commodity aid were carefully monetized and invested in milk processing and transport infrastructure, which increased capacity without disincentivizing Indian farmers (Scholten, 2010). The programme was administered and implemented by Indian organizations, and generated huge increases in income: a World Bank report (Candler and Kumar, 1998) lauded Operation Flood for the lesson that no intervention alleviates poverty so much as those that raise smallholder incomes. The programme, in which 70 percent of the 14 million farming families currently participating are landless or smallholders, owes much of its success to effective management and strong leadership by leaders of farmers' cooperatives, government support and the effective umbrella organization of the National Dairy Development Board. In the last decade India overtook the United States as the world's top milk-producing country.

National studies such as the United Kingdom Foresight Report (Foresight, 2011) explain the effectiveness of dairy development for smallholders and women. Efforts such as the Bill and Melinda Gates Foundation-funded East Africa Dairy Development (EADD) project aim to double smallholder milk incomes over ten years. EADD uses a value-chain approach to stimulate family farming and private investment in the dairy sector. Such approaches target weak links in the dairy value chain as well as improvements in dietary quality and nutrition (EADD, 2010; Nyabila, 2010; Shreenath *et al.*, 2011).

BOX 8.1

The multiple benefits of enterprise-driven smallholder dairying

Helping to achieve the nutrition, poverty and environmental Millennium Development Goals

Millennium Development Goal (MDG) 1: Eradicate poverty and hunger

Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than one dollar per day

Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger

Dairying for nutrition

- Milk is a nutritious food and can make a major contribution to household food security and income.
- Many health and stunting problems associated with child undernutrition can be tackled through simple low-cost milk fortification tailored to local needs, e.g. iron (helps prevent anaemia) and extra vitamin A (for vision, the immune system), etc.
- A daily 200 ml glass of milk provides a 5-year-old child with:
  - 21 percent of protein requirements; 8 percent calories
  - Key micro-nutrients

Dairying and women

- Organized dairying, i.e. improved productivity and market access, reduces daily workload
- Dairying provides regular cash in hand for immediate family needs

Dairying for income and jobs

- Dairying provides regular income from the sale of milk surplus for daily household and farm needs
- One off-farm job is created for every 10–20 litres milk collected, processed and marketed

Dairying for asset creation and social standing

- Dairying provides:
  - Valuable animals and their offspring
  - Collateral for loans
  - Savings for emergencies and purchase of other assets such as housing, land, etc.
  - Disposable income for purchase of household goods, clothing, schooling, etc.
  - Graduation from subsistence to commercial farming

BOX 8.1 *(continued)*

Dairying and the environment

- Dairying promotes integrated farming and optimizes use of local natural resources, including locally generated fodder, feed and crop by-products for feeding animals
- Smallholders are low energy users in the production of milk compared with producers in the industrialized countries; even lower if the huge energy costs associated with importing milk are taken into account, e.g. (i) for the energy-intensive process of drying liquid milk into milk powder in the exporting country, (ii) for transporting the milk powder and (iii) for converting the milk powder back in to liquid milk
- The manure produced by dairy animals belonging to smallholders can be used up to three times in integrated farming practice: first to produce biogas for cooking and lighting; second to fertilize fish ponds; third, as slurry recovered from ponds, which is dried and used to fertilize soil

Mendefere Dairy Association, Eritrea

BRIAN DUGDILL

Source: Dugdill, 2008.

8.2.1 Employment generation in milk production

About 12 to 14 percent of the world's population, nearly a billion people derive at least some part of their livelihood from livestock (Steinfeld *et al*., 2010). In 2005 the World Bank *Agricultural Investment Sourcebook* (World Bank, 2005a) reported that smallholder dairying was cost effective and a key source of nutrition and income to 300 million farm families globally, including 40 million in India. Mean herd size is around two cows, giving an average milk yield of 11 litres per farm per day and creating one full-time on-farm job; in developed countries over five times that

volume of milk is needed to create one farm job (FAO, 2010a). An ILRI study in Ethiopia and Kenya in East Africa and India and Pakistan in South Asia supported these findings (Staal, Nin Pratt and Jabbar, 2008a, 2008b).

In India farm-level studies highlighted the continuing importance of dairy farming in generating regular employment (Shiyani and Singh, 1995; Singh, 1997). These studies estimated that a dairy cow generated 60–100 work days per annum, depending on region, category of farm household and type of dairy cattle. On a per household basis, employment generated varied from 150 to 300 work days per year.

The livestock sector provides much more employment and regular income than rice and wheat or allied activity. Productivity of labour in dairying is about 2.5 times higher than in agriculture generally, with corresponding annual returns per unit of labour of INR 45 000 (US$1 020) and INR 17 000 (US$390), respectively. On smallholdings in India and Pakistan, employment generated per unit of milk production decreases dramatically as herd size increases (Staal, Nin Pratt and Jabbar, 2008a).

In Kenya, smallholder surveys estimate two million dairy farming households keep over five million grade or crossbred dairy cattle. Some 77 people are employed full time for every 1 000 litres of milk produced daily, equating to a total of 841 000 jobs (256 000 self-employed and 585 000 hired). Small- and medium-sized dairy enterprises represent 87 percent of this employment (SDP, 2005). In Kenya, dairy farming generates an average income per enterprise of KSh 38 000 (US$475) for small-scale farmers and KSh 298 129 (US$6 025) for large-scale farmers, with an average weighted income of KSh 114 000 (US$1 425) compared with an average per capita gross domestic product (GDP) of KSh 27 825 (US$347) for Kenya (World Bank, 2003).

Ethiopia's livestock sector accounts for 30–35 percent of agricultural GDP or 12–16 percent of GDP; dairying represents half of livestock output, and livestock contribute to livelihoods of 60–70 percent of the population (Aklilu, 2002; Ayele *et al*., 2003). A study of employment and income from all dairy-related activities for two groups of farms in the Ethiopian highlands found urban/peri-urban systems produce 205 million litres of milk annually, creating 15 000 full-time jobs, while the small-scale mixed farming system produces 900 million litres of milk annually, creating over 550 000 jobs (Muriuki and Thorpe, 2001).

Other studies show that farmers who adopt the FARM-Africa goat model in Ethiopia and Kenya can raise their annual incomes from under US$100 to US$1 000 (Peacock, 2008). There is, however, a lack of broader data on the role and potential of small ruminants and other milk species in dairy-industry programmes.

Falvey and Chantalakhana (1999) note that smallholder dairying in the tropics has not been an investment focus by the World Bank, African, Asian and other regional development banks or most bilateral aid agencies. This does, however, appear to be changing, with agencies such as the World Bank showing a renewed interest and return of a focus towards investing in agriculture. The *World Development Report 2008*, for example, concludes that agriculture alone will not be enough to massively reduce poverty, but it is an essential component of effective development strategies for most developing countries (World Bank, 2007a). The International Fund for Agricultural Development (IFAD), for instance, is increasingly supporting dairy-industry development projects.

Although high dairy consumption may be considered a health risk in some developed countries, dairy consumption is far lower in most developing countries, where the micronutrients in milk and dairy products enrich people's diets. Considering the benefits to smallholder incomes, and to the treasuries of countries that import large amounts of dairy products, the rationale for dairy-industry development is clear. Underscoring this is the fact that cattle can thrive on plant matter inedible to humans. Box 8.2 illustrates the benefits of dairying for a large, poor family in Afghanistan.

8.2.2 Employment generation in milk processing and marketing

In addition to a substantial number of on-farm jobs, the dairy sector generates significant employment in downstream industries and services. In India, for example, for every 1 000 litres handled on a daily basis, the informal markets generate:

- 10.6 milk jobs for vendors (*dudhias*);
- 20 jobs in sweet shops;
- 13 jobs in creameries that produce indigenous milk products, e.g. *paneer*, butter, ghee, cream and *dahi* (yoghurt);
- 5 jobs in retail sales of packaged milk; and
- 26 jobs in local ice-cream production (1.7 in the form of services to maintain equipment) (Staal, Nin Pratt and Jabbar, 2008a).

Extrapolating these figures to the national level suggests that up to 1.8 million dairy jobs are found in the informal processing and marketing of milk in India. A decade ago the National Sample Survey Organization database (1999/2000) estimated 1.3 million jobs in processing and marketing of milk and milk products.

Informal dairying in Lahore, Pakistan, generates nine jobs per 1 000 litres of milk while distributors and formal processors generate four and three jobs per 1 000 litres of milk, respectively. Women constituted less than one percent of employees of formal processors. Extrapolating the survey results to the provincial level, it is estimated the informal dairy sector generates 158 600 jobs in Punjab while milk-processing companies generate 3 100 jobs. Corresponding estimates for Sindh province are 32 600 and 4 200 (FAO, 2007a).

In Kenya, processing and marketing of about eight million litres of milk daily generate jobs for traders, transporters, mobile milk traders, milk bars and shops/kiosks, small and large processors, vehicle repairs, security firms and catering outlets. The number of direct and indirect jobs created in the marketing segment of the supply chain varies from 3 to 20 people per 1 000 litres traded daily. Informal marketing generates on average 18 jobs per 1 000 litres of milk handled daily, including three indirect jobs. Corresponding figures for the formal sector are 13 and one. Employees in formal processing and marketing and informal traders earn approximately the same monthly income of US$150. In contrast, the government's minimum wage guideline is US$43 (Staal, Nin Pratt and Jabbar, 2008a). A joint study by ILRI and FAO found that in Kenya "the informal sector has been growing at over 10 percent in the last decade and its share of total employment, excluding employment in small-scale farming activities, was estimated at 70 percent in 2000" (Mburu, Wakhungu and Gitu, 2007).

In Ethiopia only a small amount of milk (nine million litres) is processed into pasteurized milk, butter and cheese by large-scale commercial processors. Most

milk is processed on farm into butter and soft cheese (*ayib*) for home consumption and sale. Dairy processing and marketing nationally were estimated to create 174 000 jobs. About 94 percent of these jobs were in on-farm processing, which is dominated by women. In contrast, men dominate industrial processing (Staal, Nin Pratt and Jabbar, 2008b).

BOX 8.2

Smallholder dairying, income and well-being: case study – Afghanistan

Mr Nurullah is a farmer and lives in Chilgazi village, in the Dahdadi district of Balkh province. He has nine children and owns 1 000 m^2 of land. Prior to 2007 his main activity was crop production. He had no cow. He found it difficult to feed his family and still have some money left over to pay for education and to buy other food for the family, such as rice, oil, cereal, meat and dairy products.

In 2007 he heard about the Integrated Dairy Schemes (IDS) project through the milk producers' cooperative society and decided to join the programme.

His family life has changed. He now owns one dairy cow and has two heifers he is rearing as replacement stock. The family now has a regular income of Af 180 (US$3.6) daily from selling milk. He delivers 12 litres of milk to the village milk collection centre, and uses one litre to feed his young children and one litre milk to make yoghurt for his family.

All the income earned from milk goes directly to his wife, who decides how the money is spent.

Integrated dairy scheme, Afghanistan

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The family mainly spends the income on:

- School material: pens, notebooks, books and uniforms
- Animal feed
- Food items, such as sugar, tea, rice, cooking oil, beans and candy
- Medicines for treatment of family members

BOX 8.2 *(continued)*

The family also has benefit of:

- Manure, which is used for fuel and sold (one 50 kg bag is sold for Af 150 [US$3] every three days)
- Heifers for keeping
- Membership of cooperative; two bags (100 kg) of concentrated feed received as bonus.

Based on his experiences to date Mr Nasullah and his wife plan to have four dairy cows. "The IDS changed our livelihood; we have regular income at household level and receive Af 900 (US$18) weekly from the village MCC [milk collecting centre]. Also we are able to use milk and yoghurt for feeding our family. We hope when we reach to produce more than 50 litres milk, the MCC buy all our surplus milk".

Source: FAO, 2011a.

FAO (2012) states that poverty levels of 2 000 Afghan families were reduced by 19 percent by an FAO/GTZ project that significantly increased productivity per cow, and farmers' income from milk increased from US$1.73 per week in 2002 to US$10.20 per week in 2006. Women and children benefited and participated in these activities. Eighty-four percent of income from the sales of dairy products returned as payment to rural farmers. Increased milk production contributed to import substitution and improved food security (FAO and IDF, 2007). In Mali an FAO/World Bank dairy development mission concluded that, with the ongoing small milk processing programme, each 10 litres of milk collected could generate one full-time job annually, directly or indirectly (J.C. Lambert, personal communication, 2012). In many countries smallholders earn more from dairying than from arable crops and dairying creates more jobs than other food chains.

8.3 GENDER AND HOUSEHOLD WELL-BEING

Well-executed DIDPs contribute to improved health and well-being of people, well-being is defined as "a state of being with others, where human needs are met, where one can act meaningfully to pursue one's goals, and where one enjoys a satisfactory quality of life" (WeD, 2007). Small-scale dairying provides regular income for families and households around the world, and women are engaged in milk production, collection, processing and marketing of dairy products.

Gender is defined by FAO (1997) as "the relations between men and women, both perceptual and material. Gender is not determined biologically, as a result of sexual characteristics of either women or men, but is constructed socially". But "gender" does not denote the promotion of women only; it encompasses all of family well-being and household food security (Bravo-Baumann, 2000).

Women's traditional roles were often overlooked in development programmes directed at men who were the nominal owners of animals. Interventions sometimes resulted in higher labour input by women, while their control of production,

resources and output was unclear. In recent decades gender issues attract more attention by researchers and development partners in the design stage, and it is increasingly recognized that women's participation is a key to ensuring food and nutrition security in developing countries (IFPRI, 2005). A World Bank report, *The Role of Women in Afghanistan's Future* (World Bank, 2005b), identifies gender-responsive actions that can enhance growth, incomes and well-being even where discrimination is pervasive. It states that women play increasingly important roles in livestock production and processing of dairy products but most of women's labour is non-monetized. FAO has also observed that gender-sensitive planning enhances dairy development in Afghanistan (see Box 8.2), and highlights the direct level of cash returns to the woman of the household.

The contribution of women in reducing hunger is also emphasized in a report by the International Centre for Research on Women (ICRW): "If the global community is to increase agricultural productivity and income-generating activities in hunger-prone communities, it must … see women as central to both food security and agricultural economic development" (Bunch and Mehra, 2008). The World Bank (2007b) examined five pathways linking agriculture and nutrition and concluded that the empowerment of women is the pathway that carries special significance for household nutrition and particularly children's health and nutrition outcomes. Women were consistently more likely than men to invest in their children's health, nutrition and well-being.

Women have a significant and important role in many livestock activities and this needs to be better recognized and planned for (see, for example, the Mera Declaration of the Global Gathering of Women Pastoralists [Mera Declaration, 2010]). FAO and other agencies are mainstreaming gender issues in their livestock programmes. In Viet Nam, for example, the main income beneficiaries of an award-winning project focused on goat milk were small-scale women farmers, who not only did much of the farm work but also processed and marketed high-quality cheese (FAO, 2000).

Operation Flood in India worked with non-governmental organizations (NGOs), notably the Self-employed Women's Association and Bhagavatula Charitable Trust, who founded 6 000 women-only dairy cooperative societies (DCSs), some with the support of the Ford Foundation. These are said to operate more smoothly than their male-dominated equivalents; women, when empowered, proved more adept at the utilization of improved husbandry methods than their husbands. Since 1998, 6 000 out of 7 000 DCSs formed in India are women's societies and women continue to gain more control over the sale of milk and the use of income from it (Candler and Kumar, 1998). Moser (2006) argues that "poverty itself can be regarded as a lack of assets but also a lack of rights (social, economic, cultural, political and civil). Toward that end, working within organized groups increases the ability of women to be agents of their own development".

A similar FAO project in North Korea (TCP/DRK/0168) targeted women to improve child nutrition. Two pilot units processing goat milk were set up on collective farms to demonstrate the bulking and processing of drinking yoghurt for local school feeding schemes (FAO, 2004b). For the first time in North Korea, farmer-workers could milk their own goats at household level and sell the milk to collective processing units. Drinking yoghurt was selected because children in North Korea

were assumed to be lactose-intolerant (fermented milk products including yoghurt contains less lactose than milk; see Chapter 5).

Around Gogounou, in the north of Benin, 300 women involved in an FAO dairy development project delivered 600 litres of milk a day to a small dairy plant set up by the project, with 20 milk collectors and a team of three women for the milk processing (Bennett, 2010).

In June 2003, at the beginning of an FAO goat milk production project near Lima, Peru, six women were collecting 1 530 litres of goats milk each month; by October 2005 this had increased to 264 women collecting 21 500 litres per month. During this period each poor family in the valley saw their income increase from 200 Soles per month to 1 800 soles (J.C. Lambert, personal communication, 2012).

In 1989, the Sichuan Livestock Development Project, a project sponsored by IFAD, found that involving women in dairying increased family income and reduced the need for men to leave the village for employment (Rahman, 1995).

A study by ILRI and the national research institutes in Kenya and Ethiopia (Tangka, Ouma and Staal, 1999) confirmed the traditionally important role of women in milk production in Kenya but found that women played a much smaller role in dairying in Ethiopia. In Kenya, women alone controlled dairy income in 50 percent of interviewed households, with husbands and wives jointly controlling income in another 25 percent of the cases. On average Kenyan women constitute 70.4 percent of dairy-farm operators, ranging from 88.9 percent in female-headed households to 61.1 percent in male-headed households. In contrast, in Ethiopia women contributed only 5.5 percent of the labour involved in dairying in households with crossbred cattle, and only 5 percent in households with indigenous cattle.

The Grameen Bank/FAO integrated social dairy chain model in Bangladesh (livestock/fish farming system) increased the number of women beneficiaries from under 5 percent to over 60 percent, with over half of women rising to become Village Group Chiefs (see Box 8.6). Nobel Laureate Muhammad Yunus cites benefits of women's participation in livestock/fish farming systems which supply the Grameen Danone yoghurt plant (Grameen Bank/FAO/UNDP, 2007).

Dairy programmes such as the EADD project (Box 8.3) prepare women and youth for leadership and management at primary farmer organization, secondary dairy company management and technical levels (EADD, 2010). Results from a limited survey in two dairy business hub sites in Kenya show that increased milk production at household level translates into increased milk consumption by children and therefore improved nutrition. The challenge for farmers who intensify dairying relates to increased labour requirements for women. Recent calls for awareness raising and promotion of labour-saving technologies to mitigate possible negative impacts show recognition that family well-being and gender relations need attention as production scale rises from subsistence, to transforming, to commercial dairying.

8.4 EDUCATION AND KNOWLEDGE

Agricultural projects in poverty reduction strategies that have been implemented without strong education components have had little success (Walingo, 2006), and gender imbalance in access to education in pastoral communities has been shown to limit success of interventions (Peacock, 2008). Targeting women in technology dissemination can have greater impact on poverty than targeting men: IFPRI estimates

BOX 8.3

Feeding the 9 billion – the role of dairying

It is 7 a.m. at Kabiyet Dairies* in the emerald hills of western Kenya. The dairy is five miles down an almost impassable track, and you would think milk would turn to butter long before it arrives. Yet the place is heaving with farmers waiting for their produce to be tested, carrying it in pails on trucks, on the backs of motorbikes or on their heads. The dairy opened only 18 months ago and may seem basic, yet it has just struck a deal to sell milk to an international processing plant in Nairobi. Farmers get 26 shillings (37 US cents) a litre, more than twice what they were paid before the dairy opened its doors.

Kabiyet, Kenya

©EAST AFRICA DAIRY DEVELOPMENT

Laban Talam, a 30-year-old villager, has a smile on his face. He farms just under a hectare on a hillside overlooking the dairy. Two years ago he was scratching a living, supplementing his earnings from one cow, a native longhorn, with odd jobs outside farming. Now he has five cows, three of them Holsteins that give twice as much milk as the native breed. He rents extra land from his neighbour, has rebuilt his house, grows pineapples for export and has installed a biomass pump. His children go to a private school.

Kabiyet Dairies, Kenya

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BOX 8.3 *(continued)*

Kabiyet Dairies is only one agricultural success story among many. Brazil, by investing heavily in research, has turned itself into the first tropical farm giant, joining the ranks of the temperate-food superpowers such as America, Europe and Canada. It did so in a single generation, thanks mainly to big commercial farms. Viet Nam, through policy changes (especially freeing up small-scale private agriculture), turned itself from one of the world's largest importers of rice into the world's second-largest exporter.

So it is possible to grow more food, more efficiently, on both a regional and a national scale. But can it be done on a global scale, which is what is needed to feed 9 billion people? If so, how?

*Kabiyet Dairies is one of 68 farmer-owned milk bulking businesses being set up with support from the EADD project funded by the Bill and Melinda Gates Foundation. The ten-year project aims to double the dairy income of 589 000 farming families – approximately 3.2 million people. Kabiyet Dairies was established in Kenya in August 2009 and presently has 2 802 smallholder farming family shareholders who delivered 837 079 litres of milk in December 2010. In the same month the company made gross and net profits of 19 percent and 17 percent respectively on a turnover of US$ 368 134. Farmers received US$ 296 686 in total, equivalent to US$ 3.42 per farming family.

Source: Parker, 2011.

that yields in Kenya could increase by 25 percent if all women farmers attended primary school (IFPRI, 2005). Key recommendations include legislative reform to create equal access to resources, and the use of women's groups to support less educated people or those hesitant in speaking out due to cultural reasons.

Education, training and information networks characterized dairy development projects in the last half century. Candler and Kumar (1998) write that India's "Operation Flood can be seen as a major demand side educational project". Women with dairy earnings were able to refuse coolie work, stay home and allow their girls and boys to attend school. India now hosts 11 dairy science colleges, 31 veterinary colleges and over 80 agricultural universities (Mathur, 2000). In Afghanistan, FAO (2012) highlights training in animal husbandry, health and livelihood issues, leadership skills, policy issues, management and accounting.

FAO assisted Mongolia in establishing a National Dairy Training Centre, attached to the National Food Technology Institute for cost efficiency and sustainability. The Centre provides vocational short courses and outreach training modules on the entire dairy chain, including training for trainers. The FAO Action Programme for the Prevention of Food Losses has also shown that training farmers, farmer groups, small-scale traders and informal market agents in hygiene and food safety would improve milk quality and reduce losses.

Up-to-date information systems are needed to provide relevant data on national dairy industries, and information on available technology and training (FAO, 2005a; see also Chapter 6). FAO has a unique global perspective on this and needs to enhance its leadership and expand its capacity in providing both relevant technical information and strategic/policy advice to government and the private sector on sustainable dairy-industry development.

8.5 FOOD SECURITY, NUTRITION AND HEALTH

There is much overlap in interventions that address food security, nutrition and health; thus they are considered collectively. While this chapter reviews the impact of project and programme interventions on nutrition and health, the nutritional aspects are addressed in much greater depth in Chapters 4, 5 and 7.

During the literature review for this chapter, a gap was identified in scientific research on the impact of dairy-industry programmes on human health and nutrition. It is important to recognize that most dairy programmes do not have improved dietary intake and nutritional status as explicit goals and it is frequently assumed that such outcomes are automatic. While observational evidence from FAO and other programmes suggests that some of the milk produced by smallholders is retained for home consumption and is therefore likely to benefit household members' nutritional status, systematic analyses of the relationship between dairy production and consumption at household level are scarce, thus limiting our ability to design more effective programmes. This evidence gap is to some extent addressed in Chapter 7 of this book, which reviews available research on dairy production programmes and nutrition.

The FAO definition of food security states that "food security exists when all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Household food security is the application of this concept to the family level, with individuals within households as the focus of concern" (FAO and WFP, 2009, p. 8; see also Randolph *et al.*, 2007).

A widely used conceptual framework published by UNICEF in 1990 identifies three main underlying determinants of nutritional status: (i) availability and access to adequate food; (ii) the quality of feeding and care-giving practices; and (iii) the health of the surrounding environment and access to health care (UNICEF, 1990). Thus good nutritional outcomes can only be attained if an individual has access to a nutritionally adequate diet relative to his/her physiological requirements in combination with access to clean water and sanitation and adequate health and social care.

A varied diet composed of sufficient quantities of diverse foods is the cornerstone of food security and key to avoiding both under- and overnutrition (obesity). Policy-makers must ensure that not only sufficient staple foods are produced but a variety of micronutrient-rich foods are accessible to the world's poor and malnourished. While staple foods frequently provide the bulk of energy and protein, dietary variety is pivotal for human health, proper child growth and socio-economic development. In addition to staples, fruits, vegetables and legumes, some animal-sourced foods such as dairy products, eggs and fish are essential in a healthy diet. Some fat and healthy vegetable oils are also needed to provide essential fatty acids and to enhance the body's ability to absorb vitamin A from plant foods.

Dietary recommendations for milk and dairy products continue to generate significant interest. Many comments from around the world have been posted recently (2011) on the FAO Dairy Outlook online discussion network (FAO, 2011b). FAO and WHO are frequently asked about recommended amounts of milk and dairy products for consumption. There are currently no global dietary recommendations for specific foods or groups of commodities, with the exception of the dietary goals established for the intake of fruit and vegetables, and for fats and oils

(WHO, 2003). Most national dietary guidelines recommend daily consumption of milk. Some but not all make recommendations on the quantities to be consumed daily. Recommendations differ according to the nutritional needs of different age groups. Generally, larger quantities of milk and dairy are recommended for children and adolescents, pregnant and lactating women and the elderly, who have special requirements. For more information, see Table 4.7 in Chapter 4, Milk and dairy products as part of the diet. Neumann, Harris and Rogers (2002) reviewed animal-source foods such as milk and meat and major constituent micronutrients and their impact on child growth, cognitive development and health (see Chapters 4 and 7; also UNICEF, 1998).

As already discussed in Chapters 4 and 7, milk and dairy foods can make an important contribution to improving nutrition for women and children and are an important constituent in food products aimed at treating malnourished children. In livestock-keeping communities where milk is readily available milk and dairy products are fed preferentially to young children, whose nutritional requirements for growth and mental development are greatest between conception and two years of age.

NGOs including Heifer International, FARM-Africa and Oxfam report increased milk consumption and child growth in households raising livestock. However, the possible impact of increased income and associated purchase of animal products and improved health care is seldom considered in such reports. Smallholder dairying, especially in crop–dairy systems, contributes to food security and poverty alleviation of most smallholders in many areas of Kenya, directly through milk consumption and indirectly through income generation (Muriuki, Mwangi and Thorpe, 2001). In the Ethiopian Highlands, the introduction of improved technologies (cross-bred cows, improved feeding and management) made a significant contribution to food security and nutrition as well as to alleviating poverty (Tangka, Ouma and Staal, 1999).

While agricultural programmes, including post-harvest processing, contribute to the quality and quantity of the food supply (Peduzzi, 1990; Soleri, Smith and Cleveland, 2000), nutritional objectives are seldom integrated with main objectives or monitored. The Agriculture-Nutrition Project, a joint venture between ICRW, IFPRI, and the United States Agency for International Development (USAID) in Ghana, Kenya, Mozambique, Nigeria and Uganda, promoted stronger links between agriculture and nutrition while also considering gender (Johnson-Welch, 1999). An important observation is that women are the primary caregivers in households and many references indicate that income gained by women is directed towards family health, care and well-being.

People in low-income countries spend an average of 55 percent of their expenditures on food, as compared with 16 percent in high-income countries (Regmi, 2001). Agricultural policies that reduce production costs, create incentives to produce more nutrient-rich and diversified crops and improve access to markets can improve food supply, nutrition and income (Chavas and Uriarte, 1999; Xinshen *et al*., 2003). One example is FAO's Special Programme for Food Security (SPFS), operational in over 70 low-income, food-deficit countries, which reported that rearing livestock (with attendant income and nutritional gains) mitigates the impact of HIV/AIDS on the livelihoods and food security of affected households (FAO, 2005b).

BOX 8.4

Mongolian milk for health and wealth: Combined national school nutrition, generic milk branding and consumer education campaigns

One-third of primary school children in Mongolia are reported to be undernourished to some degree, especially during spring time following the long, harsh winter. One 200 ml glass of milk a day would contribute significantly to a school child's daily food needs in terms of protein, energy and key micronutrients and vitamins (see Box 8.1).

With these nutritional objectives in mind, the Government of Mongolia launched a school lunch scheme in 2006 for primary school children (five to ten years old). The scheme is operated under a public–private sector partnership arrangement with food companies bidding for local school lunch contracts. Following intense lobbying by the Mongolian Food Industry Association, the government insists that only domestic produce is used. Eighty percent of the meals are provided by local dairy enterprises, which purchase the milk from nomadic herders and peri-urban smallholders in the school's locality. Some 200 g of various processed dairy products are provided on alternate days together with bakery products. The scheme boosts cash flow and earnings for the concerned dairies and, in turn, milk producers.

In some cases the milk is fortified with the micronutrients that are lacking in the children's normal diets. For example, 21 percent of children under the age of ten in Mongolia are reported to be affected to some degree by nutritional stunting[1] (aggravated by vitamin D and zinc deficiency); 20 percent suffer from anaemia (iron deficiency) and 14 percent from goitre (iodine deficiency).

BOX 8.4 *(continued)*

The school lunch campaign is supported by: (i) educational posters for classrooms; (ii) milk packets with simple nutrition messages printed on the back; and (iii) a roadshow that takes awareness-raising and nutrition messages out to families in remote areas.

One of the schools in the scheme, Bayenlig Primary School, is located in a very remote area of the Gobi Desert without electricity. Most of the children are weekly borders and travel to and from school by camel. The school lunch scheme is operated by the Bayenlig Camel Herder Group, which provides a variety of conserved and nutritious camel milk products for the children.

The school lunch scheme now covers about 200 000 children across the country. The scheme is linked to the generic Mongolia milk advertising and education campaign – the first generic nutrition awareness campaign in Mongolia. In addition to supplying regular nutrition, the scheme also show-cases Mongolian milk and dairy products to children (tomorrow's customers) and their parents. In addition to the above-mentioned roadshow, the integrated campaign also includes: (i) a generic brand and logo to differentiate Mongolian milk from imports; (ii) a generic slogan, "Mongolian milk for health and wealth"; (iii) TV and movie-theatre commercials; (iv) a full-length feature movie aimed at young audiences in which a university student who drinks milk gets his girl; (v) press conferences, newspaper adverts and interviews; and (vi) billboards.

[1] Stunting is usually associated with a series of nutritional deficits during pregnancy and the first two years of life.
Source: Dugdill and Ser-Od, 2006; Dugdill and Morgan, 2008; FAO, 2008.

In conclusion there is an urgent need to consider nutrition at the programme design stage, and to develop indicators of nutritional status to monitor baseline data on nutrition. See Box 8.4 and Chapters 4, 7 and 9 for more on nutrition.

8.6 MARKET INTERMEDIARIES AND CONSUMERS

Marketing intermediaries cover all steps between primary production and consumer sales. They play important roles in linking rural markets to urban outlets. Marketing strategies must address all links in the value chain from production to consumption and consider the nature of the product, size of the market, distance between production site and the market and transport and communications infrastructure. For fresh products, organization of transport, quality control and loss minimization are critical. Appropriate technologies may increase shelf-life and extend the geographical range of markets. In developing countries, intermediaries market milk and dairy products and meet at least some consumer demands. Informal structures dominate in many cases. While these provide opportunities for local employment, there are often concerns about the composition, safety and quality of milk.

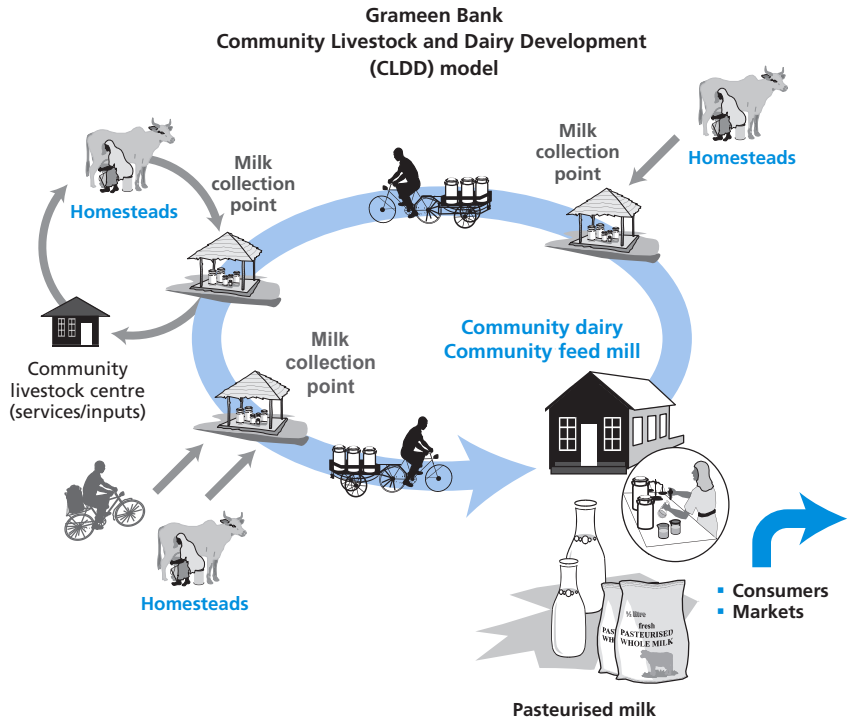
8.6.1 Marketing systems and structures

Most milk in developing countries is produced by smallholders with fewer than five animals. Their production units are widely dispersed in rural areas while most markets are in urban areas. Transport of small quantities by individual producers is not practicable or economically viable; hence, arrangements must be made for collective or specialized transport and marketing. Milk can be sold to local clients at collection centres and transported to a processing centre (or "community dairy" in Figure 8.1).

The logistical challenge of linking these producers with markets is compounded by the perishability of milk and its potential to transmit zoonotic diseases. Chapter 6 discusses these aspects and control and processing methods for preserving milk.

The first step in delivering clean, safe milk and dairy products is to produce good-quality, clean milk from healthy animals: milk from a healthy udder contains few bacteria. Additionally, natural inhibitory systems in milk prevent significant rises in bacterial counts for the first two to three hours at ambient temperatures. Cooling to 4 °C within this period maintains the original quality of milk. Various options are available to retard spoilage, including the following:

FIGURE 8.1
Smallholder dairy-industry development model from Bangladesh



- direct expansion coolers/bulk tanks
- immersion cooling
- solar-powered cooling systems (limited success)
- evaporative cooling using a moist cloth over the metal container or porous charcoal in an outer ring surrounding the milk container (limited success)
- enzyme-based preservation technologies. FAO has successfully promoted adoption of the Codex-Alimentarius-approved Lactoperoxidase System to delay deterioration of raw milk and the commercial sector is exploring other options.

Whichever system is chosen, it must be cost-effective in the given market.

Milk is processed to extend shelf-life and eliminate pathogens. Heat treatment is the most common technique. Pasteurization (heating to 72 °C for 15 seconds) is based on the time–temperature combinations needed to destroy *Mycobacterium bovis* (see Chapter 6). Low-cost, in-pouch processing has been successfully introduced by FAO in a number of countries (Dugdill, 2000).

The ultra-high temperature (UHT) process (heating milk to more than 135 °C for one to two seconds before aseptic packaging) extends the shelf-life of milk at room temperature. This obviates the need for a cold chain but does require both high-quality raw milk for processing and a high level of investment in equipment, packaging, expertise and infrastructure. There is increasing interest in extended shelf-life technologies using high-temperature pasteurization and non-aseptic packaging measures to extend milk-shelf life. The non-aseptic packaging techniques use much less sophisticated and more easily managed technology, such as in-container autoclave preservation of long-life milk.

Other techniques such as fermentation, cheese-making, concentration and dehydration, usually incorporate heat treatment. The choice of process is influenced by consumer preference, local cultures and traditions and scale of operation. In South Asia, milk sweets and curds account for a significant percentage of milk usage while cheese making is the preferred method in Latin America. In dairy exporting countries, large-scale milk powder, butter and cheese making operations predominate. Much of the milk processed in developing countries is handled in small-scale processing units using appropriate processing technologies for liquid milk and traditional milk products from a range of animal species in the different regions.

A well-organized collection system linking producers with the market is essential for the success of DIDPs. A project coordinated by FAO and involving the Government of Uganda, the African Development Bank, DANIDA, UNDP, WFP and other partners helped rebuild the Uganda dairy industry after the civil war, boosting milk availability from only 235 000 litres annually from just 500 farmers in 1986 to 26.1 million litres from 8 000 farmers by 1992. Under this programme the parastatal, government-owned Dairy Corporation was restructured and returned to profit; 64 milk collecting centres were set up or re-established; donated milk powder was monetized through the Dairy Development Committee (DDC), which channelled funding into dairy development; the Entebbe Dairy Training School and processing plant revived; and the DDC (and residual funds) became the forerunner of the current Dairy Development Authority. The Dairy Corporation was privatized in

2005, with the new owners investing US$30 million in expanding milk collection and processing infrastructure. The company now exports UHT milk and powder to other African countries and the Middle East (FAO, 2011c).

In India producers, mainly small but some large, sell fresh milk directly to urban and rural consumers, restaurants, hotels, sweet shops, small and large processors. Contract farming is emerging in India as an important form of vertical coordination in the agrifood supply chain, giving lower per-unit cost because of bulk-buying inputs and more cost-effective access to markets (Birthal *et al.,* 2008). Nestlé have successfully operated a similar system in Pakistan (FAO, 2007b). China's dairy chain has four basic modes for market organization: (i) spot market chain; (ii) cooperation chain; (iii) relation-based alliance; and (iv) entrepreneur's partnership mode (Schiere *et al*., 2007).

The World Bank (2007a) identified five issues in milk marketing: (i) lack of access to markets; (ii) weak technical capacity; (iii) difficulty in meeting quality standards; (iv) difficulty in meeting contract conditions; and (v) exposure to investment and other risks. In many developing countries quality control is difficult because of lack of trained staff, shortages of grading equipment and high cost of testing relative to value of each consignment. Emerging industrial dairy chains provide new market opportunities to Ethiopian farmers but these handle only a few percent of all milk consumed (Francesconi, Heerink and D'Haese, 2010).

Supermarkets have grown extremely rapidly since the mid-1990s in much of South America, East Asia outside China (and Japan), northern-central Europe and the Baltic, South Africa and, more recently, in eastern Africa, adversely affecting markets for some smallholders (Reardon, Timmer and Berdegue, 2004). Large processors set higher quantity, quality and uniformity standards for produce, but many smallholders were unable to afford the investments needed to meet these standards. For example, Brown (2005) found that many small dairy farmers in Argentina, Brazil and Chile could not meet standards set by supermarkets and went out of business. In the latter half of the 1990s, 60 000 small-scale dairy farmers in Brazil were de-listed by the 12 largest processors; similar patterns were found in Argentina and Chile. This shows the need for farmers' organizations to arrange collective approaches to financing to help small-scale producers meet the quality and volume trade conditions required by supermarkets.

8.6.2 Organization of milk producers

The previous section highlighted the need for efficient links between producers and consumers. Individual marketing of highly perishable commodities such as milk is not viable. Because collective action is needed to manage collection, transport, processing and marketing and increase smallholder bargaining power, DIDPs emphasize organization of farmer groups.

The type of organization varies among countries and ranges from informal groups and partnerships, through formal democratic cooperative structures, to so-called national cooperatives controlled by governments. The term cooperative means different things in different regions, but there has been an evolution towards democratic structures in most countries. In 2002 FAO published a *Milk Producer Group Resource Book,* a practical guide to setting up and operating dairy enterprises (FAO, 2002). Smallholder milk producers must produce top-quality milk at

affordable prices to participate in dairy value chains, and FAO's *Milk Testing and Payment Systems Resource Book* (FAO, 2009c) is designed to assist them in achieving this.

FAO (2009a) describes six business models for smallholder dairy chains in Asia:

- The Anand model in India and cooperative company model in Bangladesh and Thailand
- Contract farming incentive model in Pakistan (Halla, Haleeb and Nestlé models), Sri Lanka and Viet Nam
- Dairy park model in China (see Box 8.5)
- Dairy zone model, a public–private sector equity partnership in the Philippines
- Dairy chain models in Mongolia
- Social and community dairying models in Bangladesh (the Grameen Bank/FAO integrated crop–fish–livestock community model; see Box 8.6).

The three-tier vertically integrated Anand Pattern dairy cooperative model organizes smallholders into village-level dairy cooperatives, which are federated into district cooperatives and into state-level cooperatives that provide the interface with the state government's policy regulatory framework. This was the model for Operation Flood. The incredible success of Operation Flood encouraged the private sector to invest in dairying. The cooperative sector faced stiffer competition after economic reforms in 1991 and initially lost ground to competitors unencumbered by cooperative law or costs associated with providing dairy input services at village level. The sector adapted its business model and legislation to the New Generation Dairy Cooperative recently. Enterprises of the New Generation type can now be registered as producer companies under company law to avoid burdensome red tape (FAO, 2008).

The Milk Vita Project in Bangladesh is another cooperative development success story. From the mid-1970s to the late 1980s FAO, UNDP and DANIDA provided technical and financial assistance through the Government of Bangladesh to establish a sustainable cooperative dairy development programme. Today, milk is collected from 40 000 farmer-members in 390 primary village cooperatives, processed and distributed to all major cities with an annual turnover of US$9.3 million. Since start-up, average milk deliveries per member have quadrupled. A novel aspect of Milk Vita is its urban distributor cooperatives using locally made "milkshaws" – an insulated box mounted on a three-wheeled cycle rickshaw chassis – to deliver affordable pasteurized milk and dairy products to urban shops and consumers. The system created one off-farm job for each 35 litres of milk handled (FAO, 2007b).

In Pakistan the Idara-E-Kissan, commonly known as the Halla model, has its origins in a GTZ project that supported integrated dairy development in the Pattoki region of Punjab from 1987 to 1992, with processing facilities in Lahore and Islamabad. The programme has evolved from 40 villages, three centres and 1 500 members in 1992 to 22 000 members in 2007. Members elect 100 members to represent them in the executive committee who in turn elect 21 council members for a five-year period. The Idara-E-Kissan provides a range of services funded by returns from commercial operations in marketing milk. In 2006 the World Bank found Idara-E-Kissan farmer members gain substantially with:

- 37 percent higher net income
- 25 percent higher milk yields
- 13.5 percent higher price
- 9 percent more lactating animals
- 6 percent fewer dry buffaloes (FAO, 2007a).

Recently, however, the scheme has not been in operation, reportedly because of poor management.

A study in the Moroccan High Atlas Mountains showed that developing a dairy cooperative facilitated market access by reducing marketing costs and improving economies of scale (Bürll, Aw-Hassan and Lalaoui Rachidi, 2008). Similar findings were reported in other studies (Sraïri *et al*., 2009). In the 1970s and 1980s Kenya and Tanzania – with the help of FAO, DANIDA, WFP and other development partners – established parastatal dairy cooperatives. Kenya Cooperative Creameries (KCC) (originally a settler-owned dairy) and Tanzania Dairies Limited were supported for collection and processing milk nationally. Both ventures failed and revival structures are now evolving.

8.6.3 Trends in market demand

The demand for milk and milk products is influenced by socio-economic and demographic factors. The percentage of the population that lives in rural areas has stabilized at about 20 percent in developed countries and has grown only slowly since the 1970s whereas in developing countries it declined from 71 percent in 1980 to 55 percent in 2010 (UN, 2011). Growth in developing countries is such that urban populations are expected to double by 2025. Urbanization accounted for 80 percent of the world's population growth between 1990 and 2000 and the urban population reached 50 percent of the total earlier in this decade. These demographic changes have great implications for dairying in developing countries. DIDPs must be planned to satisfy consumer demands for variety, convenience, safety and concerns for animal welfare and the environment characteristic of urbanized populations. These are discussed further in Chapter 2.

8.7 REGIONAL AND NATIONAL PATTERNS AND APPROACHES

8.7.1 Dairying in developed countries

In regions with developed dairy industries, such as Europe, North America and Oceania, dairying contributed to rural development particularly in the first half of the twentieth century. Governments were very supportive in providing education, training, extension, research, and technical and policy assistance in the organization of producers' groups to improve access to inputs and services. Cooperative structures were favoured, emphasizing member education for participation in society programmes. In some cases governments gave grants and tax concessions to rural enterprises and provided assistance with export of surpluses. Under the Common Agricultural Policy of the EU, and less markedly in the United States, government support payments reportedly distort dairy trade. In 2002 Producer Subsidy Equivalent for milk (portion of farmer income derived from subsidies) ranged from 2 percent in New Zealand to 90 percent in Japan, with Australia at 31 percent, the United States at 52 percent, the EU 61 at percent and Canada at 67 percent (OECD and FAO, 2008).

Some cooperatives have evolved and formed public limited companies and partnerships that have become national and multinational corporations such as Campina in the Netherlands, Fonterra in New Zealand and Land O'Lakes in the United States.

8.7.2 Dairying in developing countries

Dairying has not featured prominently in large development programmes of many regions despite its potential to catalyse rural development. Because of the range of skills and services needed for successful implementation, national governments usually involved development agencies or used bilateral aid to support implementation of such programmes. In order to stimulate a participatory approach, emphasis was placed on organizing producers. As noted in Section 8.6.2, the type of association adopted varies.

Many countries established dairy development institutions during the last 40–50 years as part of national dairy development programmes. This section reviews some of the regional approaches used and the lessons learned from them.

Africa

Dairy development in Africa has often focused on producer groups. Formerly, cooperatives in Africa were often organs of the state and their success has been mixed. Governments planned development packages ranging from animal breeding and feeding to processing and marketing, but for a combination of reasons the plans did not fully materialize. Perhaps best known African dairy cooperative is KCC, which was formed by large milk producers before independence. After independence many of the farms were subdivided, and the government took over KCC as a parastatal institution while retaining the KCC name. Initially it was a great success but subsequently collapsed after a series of political and management scandals including the acceptance of all milk from producers. After price decontrol in 1992 and elimination of KCC's monopoly status, private enterprises and farmers' groups joined the processing and marketing sectors, and informal milk marketing expanded. In 2003 an FAO technical cooperation project assisted restructuring the Kenya Dairy Board in a comprehensive five-year plan aimed at supporting the development of the dairy industry in Kenya (FAO, 2003).

In Tanzania the cooperative movement was controlled by the government and its apex organization, Tanzanian Dairies Limited (TDL), provided milk collection, processing and marketing functions. However, TDL went into liquidation and small-scale processing emerged in the 1990s with a combination of on-farm processing, smallholder cooperatives and private vendors. A new representative Dairy Development Board, established in 2004, is now in operation and has the mandate for improving and encouraging investment in the dairy sector (FAO, 2011d).

The government dominates dairying in Swaziland. Attempts to establish independent milk producer cooperatives have had limited success, although the Matsapha Dairy Plant was privatized in the mid-1990s under the first phase of the National Dairy Development Plan prepared with FAO support.

The term cooperative was also unpopular in Malawi, so the Government developed a system of local and regional bulking groups and a national apex group. This was relatively successful in the 1980s and early 1990s, but dwindling government

resources hampered operations. A USAID-funded Land O'Lakes-implemented DIDP helped revive the industry in 2000.

In Uganda, the state Dairy Corporation began collecting and processing milk, developing marketing infrastructure and servicing milk-producer cooperatives in the 1960s. Some independent dairy cooperatives were also established then and at least two are still in operation today in Mukono and Fort Portal. The industry was jarred by civil disturbances in the 1970s, but recovered in the 1990s with the aid of an FAO/UNDP/World Bank project that ran from 1986 to 1992 (FAO, 1993). The Dairy Corporation was privatized in 2006 and producer groups function well in the restructured industry, with much of the countries milk being processed and marketed by the private sector. However, smallholders in Uganda are still without influence on the dairy value chain after milk is collected at the primary cooperative and they are fully dependant on the private dairy industry and their pricing policy. To address this, a cooperative dairy union in the Mbarara region has started the construction of one of the first large-scale cooperative processing plants in East Africa and the private sector has also recently installed a milk drying plant in the same area.

Dairying is relatively less important in western Africa than in eastern and southern Africa and milk producer organizations there are not as developed as in eastern and southern Africa. However, dairy development projects supported by FAO and others have helped to form successful producers' groups in Benin, Chad, Gambia, Ghana, Niger and Nigeria. Recently, the African Development Bank has also significantly expanded its investments in the dairy sector in western Africa in response to high demand and rising food prices.

Asia

Per capita consumption of milk and dairy products was traditionally low in Asia, but total consumption is considerable and rising so fast that a new phrase – "the myth of lactose-intolerance" – is heard, as school nutrition programmes cultivate milk drinking "while promoting future demand" (Dugdill and Morgan, 2008). However, consumption levels may not increase beyond current levels, given that some people can consume only moderate amounts of dairy products or tend to go for dairy products that are more easily digestible, such as yoghurts, probiotics, etc. Time will tell if future adults choose liquid milk or fermented milk drinks.

Demand for dairy products in Asia has doubled since 1980, increasing import dependency; the region imported were about 24 million tonnes of dairy products in 2007 at a cost of about US$14 billion. About 80 percent of milk in Asia is produced by smallholders, and tens of millions of traders and entrepreneurs, small and large, work in the informal sector. Producer organizations in India and Bangladesh are outlined in Section 8.6.2. Government has provided the impetus for DIDPs in China and Thailand. The situation in China – where investments in processing are driving growth, not always to the advantage of smallholders – is analysed in Box 8.5. In his address to the International Dairy Federation (IDF)/FAO World Dairy Summit in Shanghai in 2006 the Chinese Premier said China's "aim is ensure that every child should have a glass of Asian milk every day".

In Thailand, rapid growth in milk consumption is driven by a highly successful school milk programme (see Chapter 7 for details). Begun in 1983 with support of FAO and DANIDA, the programme was based on imported milk, but switched to

BOX 8.5

The Chinese Dairy Park Collective business model: investment-driven growth

China has one-fifth of the world's population, but produces only 4.4 percent of the world's milk. However, between 2000 and 2006, gross output of milk and dairy products quadrupled to 33.6 million tonnes. Over the past two decades per capita consumption of milk has grown from less than 2 kg to about 20 kg per year. Urban consumption is about five to eight times rural consumption, reflecting the widening income gap between town and country. Some 1.5 million smallholders (98 percent of milk producers) managing up to 20 cows produce two-thirds of domestic milk supplies; four-fifths of these smallholders have fewer than five cows.

While the world market for milk grew by an average of just 1.2 percent per year between 1991 and 2004, China's dairy market grew by a massive 16 percent annually.[1] However, the gap between supply and demand is widening and is met by imports, which totalled some 2.4 million tonnes of LME in 2007, 7 percent of consumption.

The phenomenal growth in milk production has largely taken place in the three northern province of Hebie, Heilongiang and Inner Mongolia, which by 2006 were producing 52 percent of national milk output, up from 18 percent in 1985. In these provinces smallholders are reported to earn more income from dairying than from growing crops; the profit–cost ratio of smallholder milk production is nearly double that of maize and three times that of potatoes.[2]

It is not surprising that two dairy companies from the Inner Mongolian Autonomous Region, Yili and Mengnui, are now the largest in the country, each having grown their turnovers from a few million United States dollars annually in the late 1990s to well over US$1 billion by 2007. As a result of huge investments in milk processing across China since the late 1990s, it is estimated that processing capacity exceeded demand by about 30 percent in 2003. This tended to sharpen competition among the three leading processors; as a result, farm gate prices were, and still are, depressed. Most of the spare capacity is now better utilized as demand continues to grow (up 22.5 percent in 2007), but farm gate prices have hardly changed. The reasons for this are difficult to ascertain. However, it is understood that price collusion by the large dairy companies enables them to control prices.

To keep costs low and improve milk quality, China's processors have set up a number of community-based units or "dairy parks" where smallholders keep and milk their cows. The parks, which are financed by either the processors, the local authority or the smallholders themselves, each house between 300 and more than 1 000 cows.

The key lessons for smallholder dairy development in China are: (i) the availability of cheap land and labour in the Northern Province stimulated low-cost milk production; (ii) the policy of supporting dairying from local taxation and allowing capital to be raised from the Hong Kong stock market enabled rapid expansion; (iii) the selection of capital intensive UHT milk by the processors (not by the market) enabled rapid expansion without the need to establish an expensive cold chain; (iv) price collusion

BOX 8.5 *(continued)*

A dairy park in the Inner Mongolian Autonomous Province of China

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and the dairy park model, with its captive producers, enable restrictive producer pricing; (v) policies and investment have focused on the processing side, with lending to producers generally focused on loans for breeding animals; and (vi) policies supporting producer investment further up the chains, such as in chilling systems, would increase smallholders' negotiating power with the processors.

[1] 3A Business Consulting and Shainwright Consulting and Research Group, 2006.
[2] Price Department, National Development and Reform Commission, China, 2007.
Source: FAO, 2008.

local milk to support domestic smallholders and processors. Today over six million schoolchildren get milk at school and school consumption has risen from under 5 kg per year in 1983 to over 40 kg per year and per capita consumption to 31 kg (FAO, 2008).

In 2007 the Animal Production and Health Commission for Asia and the Pacific (APHCA), FAO and the Common Fund for Commodities (CFC) organized an 18-country strategy for smallholder dairy development. The ensuing Chiang Mai Declaration – *A glass of Asian milk a day for every Asian child* – included improved household food security and nutrition as a pillar of the decade-long US$250-million investment. Based on nine country studies, the strategy (FAO, 2008) identifies major factors that influence the success of dairy development efforts. These include the following:

- Smallholders must be competitive if they are to access markets, i.e. they must produce top-quality milk at affordable prices. If they achieve this, most subsistence smallholder producers become small-scale commercial dairy farmers.
- A strategy of including smallholders requires a development vehicle sensitive to impacts of policies, programmes and activities on them.

- Appropriate technical interventions, on-farm or post-farm, must be supported by an enabling institutional environment marked by pro-smallholder policies, as well as a market structure ensuring fair prices.
- Smallholder dairy action plans, based on local context and people, are required to transform the regional strategy into national action.
- The private sector must be fully engaged in developing the regional strategy and putting the strategy into action at country level.

The strategy also notes that the smallholder dairy chain business model has been less successful:

- where central plans are used;
- when governments intervene by establishing large dairy processing enterprises managed by the public sector; and
- where low tariffs facilitated import of cheap commodities rather than local milk.

It should however be noted that the impact of such interventions depends on their timing and exit arrangements. If done for a specific purpose and duration and then scrapped as soon as their objective is achieved they may have a positive effect.

The first three investments in integrated smallholder dairy value chains under the strategy are underway in Bangladesh, Myanmar and Thailand, funded by the national governments, CFC, APHCA and FAO. The focus is on increasing income of farming families and improving food security of both farming families and urban consumers through environmentally-friendly dairying interventions: (i) profitable cows, i.e. cows that make the most money for farmers – these are invariably not the highest yielders; (ii) enhanced nutrition and market access; and (iii) enabling policy environments, including the upgrading of national dairy training centres and setting up regional training at Chiang Mai in Thailand (Dugdill, 2004).

Latin America

The dairy sector in Latin America used to be based on dual-purpose cows because meat production was the primary aim, but this is changing, particularly in Argentina, Brazil and Chile where adoption of specialized dairy breeds has raised milk output over the past two decades.

Cattle producers in Latin America and the Caribbean traditionally organized themselves in associations emphasizing meat production. Except for in Uruguay, where the dairy industry has a tradition in cooperative dairying with an export orientation, the role of milk producers' organizations was limited.

There are dairy cooperatives in El Salvador and Honduras but they depend on government assistance. The Dominican Republic and Ecuador have strong support systems for milk producers based on donor assistance. The dairy industries in Argentina and Brazil are large and complex, with a strong private sector and relatively weak producer groups. In Chile some cooperative milk collection schemes exist, and a few small groups of large producers bargain collectively with multinational processors. In Mexico, where the government regulates prices and subsidizes milk schemes, some vertically integrated producer groups supply cities, but rural smallholders are poorly organized.

Recently the Pan American Dairy Federation (FEPALE), formed with FAO support in the 1990s, helped reverse the trend of consolidating milk production in very large units by promoting both the social and commercial benefits of dairying. Argentina illustrates the dilemma of small versus large operations. Over the five years to 2010 Argentina has recorded the largest growth in net exports of dairy products after the United States as a result of huge investments in large units. In the past two decades the number of dairy units shrank from about 50 000 to 11 000. Despite this reduction, dairying still ranks sixth in job generation and fourth for equitable income distribution (Iglesias, 2010). Thus, the government is developing a new Strategic Plan for Argentina's Dairy Chain 2020 focusing on small- and medium-scale dairying.

Near East and North Africa

Milk production constitutes a relatively small share of total agricultural output in the Near East and North Africa. The sector is relatively underdeveloped, except perhaps in Israel, where high-input–high output intensive dairying is practised. Milk from small ruminants is more important than that from cows and buffaloes in some countries, but imports account for a large proportion of total supply and weaken trade balances. In most countries the share of national milk supply coming from cows is increasing as a result of programmes to develop supplies for urban centres such as Amman, Beirut and Damascus.

Government-assisted producers' groups operate in Egypt, Jordan, Lebanon and Syria but these groups account for a small percentage of milk marketed. Middlemen or traders are the principal buyers of milk at farm level. State-owned dairies are common in the region but account for less than 10 percent of products manufactured.

North Africa has been a significant importer of dairy products. Its processing and marketing chains include private, cooperative and informal systems. Small ruminants are relatively more important in this part of the region. Dairy production has socio-economic importance in Morocco, where the dairy chain provides jobs for 770 000 people, about 10 percent of agricultural jobs (FAO, 2011e).

8.8 PROGRAMMATIC ISSUES

The main elements in an organized, formal market dairy sector shown in Figure 8.2 demonstrate the complex challenges in dairy development. Elements of a less-organized or informal dairy sector include those inside the triangle plus consumers.

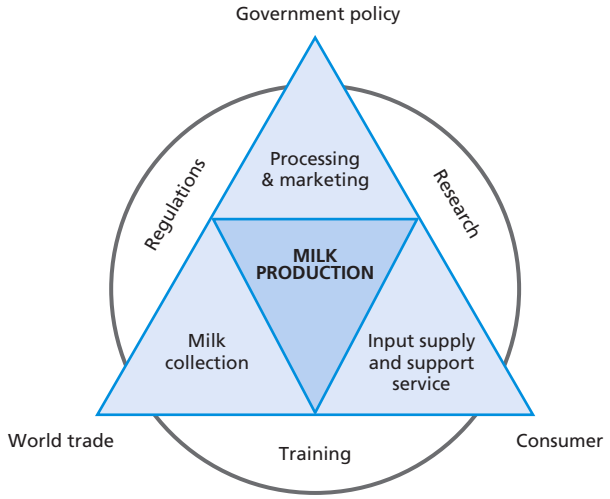
8.8.1 Factors influencing success in dairy development projects

Appropriate technical interventions, on-farm or off-farm, must be supported by an enabling environment of inclusive, pro-smallholder strategies, policies and institutional support, with markets ensuring fair pricing.

The following features are required for successful dairy development projects in all regions:

- Clear understanding of the problems – requires detailed technical and economic evaluation of market opportunities and potential to supply these markets.
- Feed and water resources – requirements and potential sources in terms of quantity, quality, cost, seasonality and sustainability of feed supply.

FIGURE 8.2
Features of an organized dairy sector



- Animal resources and breeding services – appropriate breeds and technologies to boost animal productivity and profitability.
- Adequate capital and human resources within and outside the target group. High initial investment in national capacity development may be essential in developing a sustainable dairy industry.
- Organized approach – farmers must organize to benefit from economies of scale in inputs, services and marketing.
- Strong leadership and committed producers – member education and capacity building are essential from farm to market.
- Market-oriented approach – defined objectives and long-term goals addressing all links in the value chain from cow to consumer.
- The transformation from subsistence farming (focus on food production for the family with sale of any surplus) to commercial farming (focus on market demands and effective utilization of farm resources for highest possible profit and income) – this is a major transformation for the rural population in most countries and public support is needed.
- Gender-balanced programmes – equal access to inputs and services.
- Supportive government policies – covering pricing, capacity building, research and development, enterprise development and supply of services and inputs. To be successful, these policies and structures must evolve in line with developments in trade and consumer needs in quality and safety of products.
- Inclusion of medium- and larger-scale farmers – drives the uptake of efficient technologies and systems adapted to the local environment.
- Fully integrated, environment-friendly approaches customized to the local situation.

Above all, DIDPs and programmes generating information and innovative solutions in the dairy value chain must employ evidence-based learning during formulation and implementation, and must gather baseline information on nutritional status of target populations and conduct objective monitoring to track actual or potential health and nutrition impacts of programmes.

In these processes, committed and competent people and enterprises (stakeholders) are more important than geography, climate or politics.

8.9 ENVIRONMENTAL SUSTAINABILITY

Producing, processing and distributing milk and dairy products, like other foods, affects the planet. There is increasing interest in evaluating the "carbon footprint" of discrete food supply chains from input services to primary production to consumption and waste disposal. There are limitations on the use of life-cycle analysis to assess the impact of livestock on greenhouse gas (GHG) emissions and there is a need to consider issues such as carbon dioxide emissions from land-use changes, carbon sequestration, resource-efficient use of poor-quality agricultural land and the use of feedstuffs that cannot be consumed by humans, such as crop residues and agro-industrial by-products, to reduce dependence on cereals.

Animals are often seen as competitors with humans for food staples such as maize and other grains, but this is not the case everywhere. Animals often increase efficiency of total farming systems by consuming materials with no human food value such as grasses, tree leaves, household food wastes, crop residues and by-products (Neumann *et al*., 2003; Scholten, 2010). Pradel, Yanggen and Polastri (2006), for example, conclude that, in Peru, improved rye grass pastures and improved dairy breeds offer promising alternatives in the trade-off between economics and GHG emissions.

Smallholder dairying fosters environmental sustainability in integrated farming and optimizes use of local natural resources. Methane emissions can be significantly reduced by modest increases in productivity and technological changes. On the other hand, if dairy products are imported, energy consumption is far higher (FAO, 2008). Smallholders in developing countries use little energy in milk production compared with farmers in industrialized countries. Other energy- and resource-efficient advantages include: (i) the use of animal and human power for producing feed and fodder; (ii) feeding of crop by-products that do not need additional energy to produce; (iii) relatively low consumption of energy-intensive concentrate feed; (iv) the predominance of grazing over stall feeding; (v) keeping animals in low-cost sheds or in the open; (vi) use of human power for milking; and (vii) use of manure for biogas production for cooking and lighting/heating and for fertilizing crops (Dugdill and Morgan, 2008; FAO, 2008).

Many of these features were displayed by an integrated crop–fish–livestock intervention in Bangladesh, in which smallholder dairying significantly improved the food security and well-being of 6 000 extremely poor, landless farming families in an agro-ecologically friendly way (Box 8.6). The approach is now being promoted in other poor areas of the country (Dugdill, 2007; FAO, 2007b).

Environmental issues associated with livestock, such as loss of biodiversity, land degradation, high water demand, air and water pollution and climate change are highlighted in *Livestock's Long Shadow* (FAO, 2006). The overall contribution of dairying to greenhouse gas (GHG) emissions in 2007 was about 1 969 million

BOX 8.6

Smallholder dairying, nutrition and the environment:* Crops, livestock and fisheries in North West Bangladesh

In the late 1990s the Grameen Bank was looking for ways to raise the productivity of over 1 000 fish ponds it manages in partnership with 3 000 very poor, landless and asset-less families in the northwest of Bangladesh who were earning just US$0.19 a day from their share of fish sales. The solution was to add livestock to the fish-farming system to (i) produce more food for home consumption and sale, (ii) provide manure to fertilize fish ponds to increase their productivity and (iii) shift the focus to women. The result is a profitable dairy-chain model that is part of an integrated, community-owned crop–fish–livestock system that includes joint-venture commercial milk bulking and feed-mill enterprises. The enterprises are jointly owned by Grameen (30 percent) and village-group members (70 percent).

Following training and build up of savings through their village groups, the families access small commercial loans for livestock and other income-generating activities. Loans may be selected for in-calf heifers, cows with calves, store cattle for fattening, goats, pigs, poultry, ducks, crops/fodder, "milkshaws" (rickshaws for transporting milk and other commodities to market), biodigesters and, more recently, vegetables, fishing gear and social forestry. Though many of the poorest families started with loans for small livestock and poultry, they soon shifted to larger loans for dairy cows, which offer higher returns in terms of profits, nutrition, asset accumulation and social standing.

Once smallholders have four or five cattle, they have enough manure to take out a loan for a biodigester to produce gas for cooking and lighting. The spent slurry from the biodigester is then used to fertilize and increase the productivity of fish ponds. The ponds are emptied every two or three years and the slurry is dried and used as crop fertilizer. In this way smallholder dairying has become an important component of an integrated and environmentally sustainable farming system. While in some ways the model is a social dairying model, it is commercial in operation. Over the seven-year life of the pilot project (2000–2006) benefits included the following:

- Improved nutrition: Before the project no households consumed milk; by 2006 all 6 000 households with cows (including 3 000 additional households that joined the programme after it started) consume 0.2–1.0 litre of milk daily. Before the project 52 percent of families reported having enough food; by 2006 98 percent said they had enough food.
- Increased earnings: Average earnings from fish and milk increased from US$0.19 to US$1.25 per person a day (excluding sale or value of livestock born). Most of this increase came from milk sales. These earnings enabled households to purchase essentials such as food, schooling, clothes, etc.
- Accumulation of physical assets (excluding livestock): Household assets increased by 145 percent, including investment in tube wells for safe water, improved housing, biodigesters for clean cooking and lighting, sanitary latrines, etc.
- Increase in number of women beneficiaries: The number of women benefiting directly from agriculture increased from less than 5 percent to more than 60 percent; more than half of the village-group chiefs are now women.

BOX 8.6 *(continued)*

The key lessons of this project for smallholder dairying and the environment are as follows:

- Dairying can help lift smallholder households out of poverty.
- Community-based pro-poor dairy initiatives provide an effective entry point for improving family household nutrition while sustaining the environment that can be replicated in similar conditions.
- These types of model should be promoted and adopted under national strategies for accelerated poverty reduction and national livestock policies (as they are in Bangladesh).

Women receiving goats

COURTESY OF HEIFER INTERNATIONAL

Milk contributing to income and good nutrition

©FAO/G. DIANA

Women cooking on an improved stove

COURTESY OF HEIFER INTERNATIONAL

The agro-ecologically friendly model is currently being scaled-up and out to other poor regions in Bangladesh.

* *Source:* Dugdill, 2007.

tonnes of CO_2-equivalent from "milk production, processing and transportation, as well as the emissions from meat production from dairy-related culled and fattened animals" – about 4 percent (2.7 percent milk alone) of total anthropogenic emissions (FAO, 2010a). Growing and providing food does entail some environmental effects and efforts are ongoing in the dairy sector to reduce the intensity of emissions (FAO, 2010b). The IDF-led Global Dairy Agenda for Action on Climate Change includes initiatives introducing best practices for reducing GHGs. The alliance behind the Agenda includes IDF, FEPALE, the Strategic Agriculture Initiative Platform, the International Federation of Agricultural Producers, the European Dairy Association, the Eastern and Southern African Dairy Association and FAO.

8.10 KEY FINDINGS

The following key findings and insights have emerged from this chapter:

- Dairy-industry development aimed at smallholders enhances development opportunities for women and young rural people. Empowerment of women has a significant effect on household nutrition outcomes, particularly children's health, well-being and development.
- There are huge opportunities for dairy-industry development as market demand follows rising incomes, especially in emerging African and Asian economies. Careful programme design can quickly bring nutritional benefits to vulnerable children, especially pre-school children, and grow future demand. Children are tomorrow's consumers.
- Dairying generates more jobs and income per unit of land than do crops. Estimates of up to one off-farm job for every 30 litres of milk collected, processed and marketed are reported.
- Dairying is an important tool for sustainable rural development in many areas and has lifted millions of rural people out of poverty. It provides more regular, reliable income than other agricultural operations, particularly crops, but can be riskier because of the longer-term investment required. Understanding of risks and adoption of suitable risk-mitigation strategies are critical elements of any DIDP.
- Informal marketing systems account for over 80 percent of milk marketed in many developing countries and generate more jobs per unit volume than formal processing and marketing of milk and dairy products. These systems will remain important in value chains producing and delivering milk and dairy products to low-income rural and urban communities for the foreseeable future.
- Programmes must help more smallholders shift from subsistence farming to profitable, commercial dairying approaches. The private sector must be encouraged to invest in smallholder milk production to ensure that smallholder farmers obtain a fair share of the value and benefit of dairy-industry development.
- The private sector must be fully engaged in development and implementation of dairy-industry development strategies at country level. Vertical coordination in the milk value chain through producer organizations provides cost-effective access to inputs, services and markets.
- Successful dairy-industry development projects and programmes give high priority to education and training and long-term investment in national capacity building for sustainability.

- A balanced diet is a core part of food security. More emphasis is needed on nutrition outcomes of DIDPs. A concerted effort is needed to help dairy stakeholders and consumers better understand the benefits of milk and dairy products in terms of food security and nutrition.
- Urbanization and market demand influence product profiles. Policies, structures and strategies must evolve to meet consumer needs for improved food and nutrition security and environmental sustainability.
- Future DIDPs should monitor nutrition and agro-ecological outcomes using clear performance indicators. They must incorporate evidence-based learning and be of sufficient duration and scale to effect lasting, beneficial change.

Manifestly, dairy industry development pays, economically and socially. That said, there is room for improvement, above all to emphasize nutrition benefits and issues. Such nutrition issues are listed below and are discussed in more detail in Chapters 7 and 9.

- **Design:** DIDPs should provide for improved household nutrition, increased income generation and environmental sustainability. To be inclusive for smallholders, they need to designed as progressive and motivate **stakeholders to invest in more market-oriented and commercial dairy-enterprise activities.**
- **Value-chain approach:** DIDPs should be inclusive to balance social outcomes with enterprise objectives along the farm-to-consumer chain to ensure sustainability.
- **Nutritional outcomes:** Practical indicators and measures of nutrition and health outcomes need to be developed and be applied to inclusive DIDPs.
- **Nutrition decision-makers:** At household level, nutrition decision-makers are almost always women. They need to be targeted when delivering nutrition awareness and education messages under DIDPs and enabling policies that promote inclusive dairy-industry development approaches
- **Scale and duration:** DIDPs can be delivered at scale; several outstanding programmes have benefited millions of rural producers and urban consumers. On the other hand, most recent dairy projects are of short duration. A balance must be struck between scale and duration to effect lasting and sustainable nutritional change. In addition, the generation of data from full-scale operations would be useful to objectively measure the nutritional impact of dairy-industry programmes.
- **Interface between public and private sectors:** FAO has a unique ability – based on specific knowledge and focus on inclusive dairy industry development, including institutional development, knowledge-based learning and its position as an impartial broker – to effectively leverage and tailor partnerships between the public and private sectors to guide member countries and development partners in delivering sustainable and inclusive DIDPs. Its comparative advantages of cross-cutting technological expertise could be more effectively mobilized through additional core resources which could be accessed by member countries, the private sector and dairy-industry development and financing partners.
- **Investments:** Investment in dairying in developing and transition countries should be aimed at ensuring inclusion of smallholders and tailored to national

and regional specificities. FAO and others can help guide both member countries and, increasingly, partners in the public and private sectors, including the international finance institutions.

8.11 KEY MESSAGES

- Dairying can provide immediate and multiple benefits at household level for farm families and often for women.
- DIDPs should be designed and implemented to optimize inclusion of smallholders and their organizations.
- DIDPs should include nutritional outcome as an indicator of project impact (and success).

DISCLOSURE STATEMENT

The authors declare that no financial or other conflict of interest exists in relation to the content of the chapter.

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Chapter 9

Human nutrition and dairy development: Trends and issues

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ABSTRACT

This chapter highlights key trends and emerging issues in dairy development and human nutrition and discusses their implications for the future of the dairy sector, particularly in developing countries. The steady and continuing growth of the dairy sector is an important trend, although there are considerable regional differences in the rate of consumption growth. Together with growth has come public and private investment, with the private sector dominant in countries belonging to the Organisation for Economic Co-operation and Development (OECD), Argentina and Brazil, and public-sector-led programmes being prime movers elsewhere. Dairy products are an excellent source of nutrition, important in diversifying the diet and improving the nutritional status of poor people, particularly pregnant women and children above the age of 12 months. However, the poorest families and most urban dwellers do not own dairy animals and find the price of dairy and other livestock products too high. Indirect and direct support measures are necessary to improve poor people's access to livestock products while still allowing producers to make a reasonable living. Lengthening value chains bring the need to establish institutions and practices that promote the safety of dairy products. The most vulnerable members of the population are at particular risk from unsafe food. Minimizing these risks requires actions pre- and post-harvest. Overconsumption of animal-source foods carries health risks; however, milk and dairy products have not been implicated in causing obesity or increased cardio-vascular disease (CVD) and their consumption may reduce the risk of certain metabolic problems. The livestock sector worldwide is scaling up and intensifying, but the trend has been slower in the dairy sector than for most other livestock. This suggests that small-scale commercial production may be more sustainable for dairy farmers than for owners of other livestock. The impact of scaling up is affected by the speed at which it is done and the strength of local institutions in supporting smallholders. Dairy products are far less traded internationally than meat; nonetheless, dairying is still a global industry in which multinational companies sell processed products to a wide range of markets to supply wealthy consumers and the baking and fast-food industries. World milk prices and milk imports affect the functioning of domestic markets in developing countries. The dairy sector has a two-way relationship with the environment. On the one hand it is implicated in the production of greenhouse gases and contributes to climate change. On the other hand, dairy production is

affected by the availability of natural resources and must adapt to climate change. New collaborative initiatives between the private sector and international agencies will be important in making these adjustments. Integrating nutrition and agricultural development seems intuitively obvious, yet often this link is not made. The chapter explores ways that links could be rebuilt between dairy development and nutrition by making nutritional goals more prominent in dairy-industry development and other dairy programmes. Although well-designed dairy-development programmes appear to have improved nutrition and livelihoods, solid evidence is scarce. Few of these programmes have started with the primary intention of improving nutrition in vulnerable groups, or have measured nutritional impacts. The chapter proposes that dairy development with public or private funding should more explicitly pursue nutrition objectives. Governments, development agencies and the private sector all have roles to play. Nutrition-sensitive dairy-industry development is likely to be more effective if it is applied in an environment where there is high-level political commitment and improved nutrition is generally promoted, and where intersectoral collaboration is already the norm.

Keywords: Nutrition; dairy sector development; smallholder production; policy

9.1 INTRODUCTION

There are many publications on dairy development and even more on human nutrition, but this book is unusual in examining the extent to which it is possible to make explicit connections between the two. The previous chapters provide a rich mine of material on the role of dairy products in human nutrition and the way that investment in dairy-industry development[55] and other dairy programmes has changed. This chapter draws together the threads of the two stories, on nutrition and on dairy development, by considering seven key trends that emerge from the information presented in Chapters 2 to 8 and highlighting the issues that arise from them. It then discusses the implications of these findings for the future of the sector, particularly in developing countries.

9.2 KEY TRENDS AND EMERGING ISSUES

9.2.1 The dairy sector: continuing to grow

Dairy continues to be a growth industry, as highlighted in Chapters 2 and 8 which describe the steady expansion of demand, production and investment. Dairy has not experienced the same fast rise as the poultry sector, but demand for milk and dairy products has seen an upward trend that projections suggest will continue. This trend has been driven by several global developments. More people, who are on average becoming richer, and increasing concentration of populations in towns and cities all

[55] Note: this chapter follows the convention used in Chapters 7 and 8 of distinguishing between "dairy-industry development programmes" (activities that ensure milk and dairy products are available, affordable, nutritious and safe by helping small- and medium-scale dairy producers, processors and service providers to maximize their capacities to meet demand) and "dairy programmes" (programmes in developing countries where milk or dairy products were part of an intervention and nutrition was affected).

add up to a growing demand for milk, ghee, butter, cheese, yoghurt, ice cream and dairy desserts. With rising incomes in parts of the developing world and an increasing interest even in places where dairy products were not traditionally consumed, demand for a diverse selection of dairy products can be expected to keep growing.

The diversity of milk sources and dairy products is also likely to have played a part in demand growth. As described in Chapters 2 and 3, milk is produced for human consumption by at least 11 species of animals and is processed into a wide range of products that cater to local preferences. Cattle and buffaloes produce most of the milk consumed worldwide, but interest in goat and sheep milk has increased in recent years. Milk from a range of other minor dairy animal species is locally important in some parts of the world.

At the same time, strong growth in dairy production and consumption has been limited to certain regions and countries. The developed countries remain the largest consumers of dairy products per person and have dominated dairy processing and exports, but they have seen negligible demand growth in the past 30 years (Chapter 2). The most dramatic growth in per person terms has been in China, with the rest of East and Southeast Asia, South Asia and Brazil seeing smaller but still important rises in consumption. In China, urbanization and government promotion of dairy each may be playing a part, with urban people consuming around three times as much dairy products as rural dwellers (Chapter 2). In South Asia, the growth in total demand has been remarkable, although in Bangladesh average consumption per person is still low for a country where dairy products are integral to the diet. In Brazil demand for milk has grown although demand for meat has risen even faster. Equally interesting are the regions where consumption has not grown. Milk is important in the diets of northern, eastern and southern Africans and there have been a number of smallholder dairy projects in sub-Saharan Africa, yet consumption per person in most countries has stagnated or decreased. Low incomes have contributed to stagnation; milk, like other livestock products, is income elastic, meaning that as people rise out of poverty they consume more. As incomes rise in the developing world, there is still potential for demand to grow in areas where it is currently weak.

Together with growth has come investment from both public and private sectors, described in Chapter 8. Again there are regional differences. In the developed world and Argentina and Brazil the private sector has been the major investor in developing a global industry led by a small number of multinational dairy firms. In 2009, the top ten dairy companies in the world, with a total turnover in dairy products of US$114 billion, were multinationals based in Europe, New Zealand and the United States (Rabobank, 2010). In Argentina the industry is led by about ten national and multinational companies (FAO, 2011a); in Brazil six multinational and eight national firms dominate the sector (Chaddad, 2007).

In Asia, however, public-sector-led programmes have been prime movers, although joint public–private efforts have recently become more popular. The Indian Government put state funding into the Operation Flood programme for many years and is now borrowing US$352 million from the World Bank to invest in the dairy sector (World Bank, undated). Large non-governmental organizations (NGOs) and co-operatives, such as Amul, have also played an important part in dairy-industry development in India, and there is an increasing although still small

investment from national companies. In Pakistan, the public sector has provided the bulk of investment but both local and multinational private firms have brought technology into the dairy sector and built up market chains. The current Association of Southeast Asian Nations (ASEAN) Smallholder Dairy Development Plan as developed by FAO is a public–private strategy with a budget of US$250 million, and northern China has seen large public–private dairy-industry development projects. In some African countries total investment in smallholder dairy-industry development programmes over the past few years has been quite sizeable – around US$120 million in West Africa and US$110 million in Kenya – yet many individual projects have been small, with NGOs acting as prime movers.

Growth in the dairy sector brings with it the need to establish institutions and practices that promote food safety. Chapter 6 emphasises the importance of both the public and the private sector in promoting food safety, including the establishment of food-safety standards and provision of guidelines for practices to minimize risks from zoonotic diseases, pathogens and contaminants, as well as measures to support compliance with standards and guidelines. Investment is needed throughout the market chain – in hygiene and cooling facilities at farms, quality-management systems at processing plants, clear labelling of dairy products sold and education for those involved in producing, preparing and handling food.

9.2.2 Dairy products: an excellent source of nutrition but expensive for the poor?

Latest estimates indicate that approximately 870 million people are chronically undernourished, meaning that their energy intake is below the minimum level agreed internationally to be adequate (FAO, IFAD and WFP, 2012). Even those who consume sufficient energy may not be nutritionally secure; it is estimated that almost two billion people are deficient in one or more micronutrients, mainly because of eating poor-quality diets (Chapter 1). Poor health and unhygienic food preparation practices reduce the nutritional value obtained from food and contribute to undernutrition. Many of the world's malnourished people are children from poor families, of whom 2.5 million die each year from malnutrition-related problems (FAO, IFAD and WFP, 2012); many of those who survive will grow up physically stunted or fail to develop their full cognitive powers. Large numbers of malnourished women go on to give birth to underweight babies. Furthermore, maternal undernutrition is an important determinant of child undernutrition, which contributes to an intergenerational cycle of growth retardation (UNSCN, 2010). As people's productivity is low when they are poorly nourished, compromising their income earning potential and their ability to lift themselves out of poverty, malnutrition perpetuates the cycle of poverty.

Dairy products[56] can be important in diversifying the diet. They are energy-dense and provide high-quality protein and micronutrients in an easily absorbed form that can benefit both nutritionally vulnerable people and healthy people when consumed in appropriate amounts. Milk and dairy products can be important

[56] In this chapter milk and dairy products refer to cow milk and products from cow milk unless otherwise specified.

sources of calcium, magnesium, selenium, riboflavin, vitamin B_{12} and pantothenic acid (vitamin B_5) (Chapters 3 and 4). Milk from some animal species can also be a source of zinc and vitamins A, C, D and B_6 (Chapter 3). However, milk does not contain sufficient iron and folate to meet the needs of growing infants, and the low iron content is one reason animal milks are not recommended for infants younger than 12 months (see Chapter 4). There is evidence to suggest that adding dairy products to the diets of undernourished pregnant women and children above the age of 12 months is beneficial for child development and general health (Chapter 4).

Although currently milk production is dominated by cow and buffalo milk, promoting the consumption of milk from a range of animal sources may be beneficial. There are large differences in nutrient composition among milks from different dairy species (Chapter 3). It is not possible to recommend one particular milk as the "best milk", as this would depend on the specific nutritional needs of the population group or individual in question. Milk from minor species can be important in parts of the world with access to only a limited variety of other foodstuffs. In landlocked Mongolia, for example, populations with no access to n-3 fatty acids[57] from fish benefit from intake of mare milk (Chapter 3).

It seems highly likely that there would be an improvement in the food security of the poor if more dairy products were added to their diet (Chapter 4). Milk, yoghurt, ghee and cheese are known and accepted foods in many cultures, making it easy to encourage people to consume them. Dairy products in the correct quantities are good for most people over 12 months of age, providing essential nutrients in an easily digestible form.

Perhaps the greatest impediment to increasing consumption of dairy products by the poor is their price. Like other animal-source foods, dairy products tend to be an expensive source of energy compared with cereal staples. While at times of economic stress livestock products are replaced by other proteins or starchy staples, consumption of animal products generally rises as incomes rise (FAO, 2009). Dairy products are no exception. In China, for example, consumption of dairy products per person grew considerably between 1987 and 2007, with this rise occurring during a period of considerable economic growth and poverty reduction (Chapter 2). In India, the nutritional status among certain populations in the country has not improved or improved only marginally, despite unprecedented economic growth in recent years. Although milk production increased fourfold in India between 1963 and 2003, evidence suggests that consumption is restricted to the more affluent because of the cost of dairy products, which may partially explain the so-called "Indian enigma"(Chapter 2; Headey, Chiu and Kadiyala, 2011).

Milk is a staple in the diet of many rural families. This is particularly true for pastoralists, while small-scale intensive dairy production using cows and goats has provided a way for farmers in Asia and Africa to earn a steady income (Chapters 2 and 8; Ogola and Kosgey, 2012) and has increased home consumption in families that keep dairy animals (Chapters 2 and 9, citing reports from Kenya; Chapter 7,

[57] n-3 or omega-3 fatty acids, together with n-6, are known as "essential" fatty acids, i.e. they cannot be produced by the human body but must be ingested in food. n-3 fatty acid is associated with brain function and reduced risk of heart diseases.

citing reports from Ethiopia and Bangladesh). Support to small-scale dairying can therefore improve livelihoods and increase food security in rural areas. Using species other than cows also increases the accessibility of dairying to poor rural families.

However, the poorest rural families seldom keep dairy animals and for them milk can be expensive. Poor urban families also have limited access to livestock products, including milk, because of their cost. Urban livestock keepers are for the most part restricted to the fringes of residential areas (FAO, 2011b), where keeping animals allows them to diversify livelihood-generating activities and provides a source of locally produced food products for people living in the vicinity of the livestock keepers (Güendel, 2002). For most urban families, growing vegetables or keeping chickens is easier to manage than dairying, and for some home food production is not possible. Ruminants, which need large quantities of forage, are particularly hard to manage in confined urban spaces. Thus, the majority of urban populations must buy their food and may often eat outside of the home. For those who can afford it, consumption of dairy and other animal-source foods has risen, but dairy products remain out of reach for many others.

It is not a simple matter to make animal-source foods cheap enough for poor people to afford them; this is particularly true for those poor who are net food purchasers, a group that includes all of the urban poor and many of those in rural areas (FAO, IFAD and WFP, 2011). The same policies cannot necessarily be counted on to promote sustainable income for farmers and cheap and nutritious food for consumers. Measures to ensure that the poorest people have access to adequate food are indispensable. These may include indirect subsidies and support for technology adoption as well as direct support to increase consumption. The nutrition of women and children can be targeted directly through dairying by: (i) supporting poor families to produce and consume milk at home; and (ii) supporting school feeding programmes that include milk. There are advantages to doing both at the same time. Well-designed school feeding programmes, including those that supply milk, have the dual benefit of providing children with supplemental nutrition and encouraging parents to send their children to school. They can be introduced in both rural and urban communities. School milk programmes are fairly widespread in middle-income countries and have been shown to improve child nutrition (Chapter 7) but they are not the whole answer; in particular, they do not reach younger children and their mothers, who are generally at greatest risk of malnutrition. Since good nutrition in the first 1 000 days of life has been shown to be critical for physical growth and mental ability,[58] programmes are also needed that reach women and young children at home. Two such programmes are described in Chapter 7: the National Complementary Food Programme in Chile, which targeted pregnant women and children under 6 years, and the Liconsa programme in Mexico, which successfully used iron-fortified milk to reduce anaemia in children aged 1 to 11 years.

The safety of dairy products is an important element of their nutritional value. The most vulnerable members of the population – those who are undernourished, the immune-compromised, infants and children, pregnant mothers – are all at

[58] http://www.thousanddays.org

particular risk from unsafe food. Chapter 6 discusses the risks that certain types of dairy products may pose to vulnerable groups. These include *Listeria* species, which may occur in soft cheeses and pose a risk to pregnant women, and the risk of meningitis and enteritis in infants linked to presence of *Cronobacter* species in powdered infant formula. Food is only one possible exposure route; women handling infected dairy animals are at particular risk of contracting brucellosis, a potentially debilitating illness.

Minimizing these risks requires actions pre- and post-harvest. For example, transmission of *Brucella abortus* and *Brucella melitensis* from dairy animals can be kept to a minimum through regular vaccination of the animals. Many risks can be reduced by ensuring hygiene during milking and thermal pasteurization of milk. Dairy-industry programmes have a responsibility to promote food-safety practices among producers and processors.

9.2.3 Growing cities: changing diets and new opportunities

More people now live in urban areas than in rural areas, and in growing economies of the developing world cities are expanding as people move in from the countryside in search of employment and new opportunities (Chapter 2). Increasing urbanization and the associated lifestyle changes are probably the most important factors in dietary change and subsequent changes in nutritional status. As people move from rural areas and settle in cities their relationship with food changes; they produce less of their own food and are distanced from the farm. Some city people still keep livestock but for the most part livestock-keeping is restricted to the fringes of residential areas (FAO, 2011b).

All urban consumers, rich and poor alike, must rely increasingly on the assurance of others that their food is safe, since they can no longer see where it comes from. The geographical distance between production and consumption and the many links in food market chains leading into urban areas mean that food-safety regulations and practices, including traceability of products, play a critical part in urban nutrition. This problem is not unique to dairy products – it applies to all foods. When milk is produced within city limits, it is important it is produced in a clean environment and to ensure that those involved have access to information about safe production, processing and supply. Integrating food-safety practices into household and community food-production initiatives in urban areas has recently been identified as an urgent area of research (Girard *et al.*, 2012).

Malnutrition in growing cities has two faces, with underconsumption and overconsumption found side by side. The urban poor face the challenge of finding cheap, nutritious and safe food, including livestock products, in places where they can easily access it. For those who can afford sufficient food, easy access to energy-dense, nutrient-poor foods can lead to obesity and other chronic diseases. Since urban populations in developing countries are on average richer than those in rural areas, they have tended to increase their consumption of animal-source foods, edible oils and sugar-sweetened food and beverages, including carbonated drinks.

Although dairy products are energy-dense and high in saturated fatty acids, they have not been implicated in causing problems associated with overnutrition. Dairy products have not been associated with obesity (Chapters 4 and 7), nor is consumption of low-fat milk and dairy products associated with increased CVD risk; it may

even contribute to reducing CVD. Consuming milk and dairy products may reduce the risk of metabolic syndrome and type 2 diabetes in adults (Chapter 4). Several studies suggest that milk may offer protection against colorectal cancer and possibly bladder cancer, although limited evidence suggests that high consumption of milk and dairy products is a cause of prostate cancer (Chapter 4).

It appears, therefore, that there is no special need to target overconsumption of dairy products. A more pressing need is to improve the urban poor's access to milk and milk products.

The nutritional challenges facing people living in growing cities are well known, but cities also offer opportunities for developing new products and promoting healthy lifestyles. Cities offer large, compact populations that consume more animal-source foods than rural people (Chapter 2), providing a ready market for dairy products. Economies of scale, higher incomes and the willingness of city populations to try new diets also make it attractive to invest in new products that boost nutrition, such as fortified foods, fermented foods and foods with specific dairy components, such as lactose and fat, either removed/reduced or added via processing for consumers with special diets and specific intolerances (Chapter 5), or products with increased shelf-life, such as ultra-high-temperature-treated yoghurt. As innovative products become more common, a regulatory framework is needed that assures the safety and quality of products and protects the consumer from misleading information and fraudulent practices (Chapters 5 and 6).

As access to diverse types of food does not guarantee healthy nutrition choices, the easy access to communication and active social networks in cities should be exploited in order to provide people with better information about dairy products and nutrition.

The economies of scale of large, dense populations make it possible to initiate urban nutrition programmes like those of Belo Horizonte in Brazil (Lappé, 2009), which started a food-security programme in 1993 to end hunger within the city. Using a range of initiatives that include provision of free school meals, subsidized meals in designated "People's restaurants", support of local food production, improved distribution in poor parts of the city, community and school gardens and nutrition education, impressive reductions in child mortality and malnutrition rates have been achieved.

9.2.4 Scaling up: implications for food supply, food safety and farmer livelihoods

The livestock sector worldwide is scaling up[59] and intensifying[60] in response to population growth, economic development and technological changes (FAO, 2009). However, the dairy sector has scaled-up and intensified more slowly than other livestock sectors such as poultry and pigs (FAO, 2009). The difference has occurred for a number of reasons. One relates to government policies in much of South Asia and parts of Central Asia and Africa, which have either positively encouraged small-

[59] Scaling up in this context refers to production and processing units becoming on average larger.
[60] Intensification is the process by which production and processing transition from low to higher inputs.

holder production or failed to discourage the informal markets on which smallholders depend (Chapter 8). Elsewhere, notably in Argentina and Brazil, policies have encouraged private-sector investment in medium- to large-scale enterprises, and in these countries smallholders have gradually moved away from dairying. Other factors relate to the nature of dairying and dairy supply chains.

Factors that tend to accelerate scaling up include supply chains dominated by large retailers and the expectations of consumers related to food safety, quality and diversity. Both of these add to complexity and cost on farm. If a requirement is introduced for on-farm milk cooling, for example, this is only cost-effective above a certain volume of production. Chapter 8 cites the examples of Argentina, Brazil and Chile, where many small-scale dairy producers went out of business when they could not meet quality standards set by supermarkets and processors.

Factors that tend to slow the rate of scaling up include complex supply chains, the use of local technology and processing methods to improve the shelf-life of products, and local institutions such as producer groups and co-operatives that allow farmers to achieve economy even at a small scale. Dairy groups have been popular and in many places successful, as Chapter 8 describes. The labour market also affects the attractiveness of small-scale dairying. Production, trading and processing on a small scale are labour intensive – Chapter 8 describes the benefits of small-scale dairy-industry development programmes in generating employment for hundreds of thousands of people. Where other opportunities are scarce and families assign a low value to their labour, small-scale dairying is attractive. In peri-urban areas with other options, it may be less so. The ability to produce relatively efficiently on a small or medium scale using family labour has contributed to the relatively slow scaling up of dairy compared with other livestock sectors.

There is no indication that intensification and scaling up in the dairy sector will speed up to compare with rates seen in the poultry sector unless there is a rapid shift in government policy in South Asia and Africa towards favouring large-scale dairy production. This means that smallholder production in the dairy sector may be more sustainable than in other livestock sectors.

Scaling up is likely to have different consequences in urban and rural settings. For rural producer-consumers of dairy products, scaling up has the potential to remove a steady source of income and an immediate source of food. Dairy-industry development has been seen by the international community as a good thing for smallholder farmers, primarily because of its potential to generate income on a daily basis. There can also be positive impacts on nutrition in farm families if women control the use of milk or the money from its sale.

Although Chapter 7 points out that the evidence linking dairy-industry development or other dairy programmes with nutritional impact is scarce, various studies have indicated that attention to gender issues, good education on nutrition as well as dairy production, and the use of goats or sheep in addition to cattle for dairy production have all improved nutrition in smallholder dairy households. These households are not, it must be admitted, the poorest of the poor – poor families do not normally keep dairy cattle although they may keep dairy goats by grazing them on common land. Many other people who do not own animals but take part in managing, trading and processing them can also improve their livelihoods and, it is assumed, the nutrition of their families from small-scale dairying.

The impact of scaling up on small-scale farmers will depend partly on the speed at which it is done. Companies investing in dairying usually buy into existing market chains through existing companies and hence use their contract arrangements for local farmers and traders. Over time, the less competitive operators drop out and the market chains concentrate. This effect may be positive or negative for producers in remote areas, who can generate a reliable daily or weekly income and not just food if they are connected to urban markets. It can also affect the ability of medium-scale dairy processors to find enough milk to keep their plants operating. Even the most entrepreneurial may face high transport costs because of distance and are, to a great extent, price takers, as they must sell their milk on the day that it is produced. Scaling up can be favourable for them if it enables them to operate under a fair and reliable contract with a company rather than relying on spot-trading with milk hawkers – but not if a monopoly takes away their power to negotiate. In the Philippines and Thailand, contract farmers producing pigs and poultry benefitted from fixed contracts at a time when world-market prices for their products were falling (Delgado, Narrod and Tiongco, 2003). In the USA, however, contract farming has been reported to reduce both independence and profits (World Bank, 2005). It is here that the development of local institutions such as cooperatives and dairy groups can improve negotiating power and market access and provide economies of scale in milk preservation and collection.

In urban settings, scaling up offers the potential to provide a steady supply of safe food. However, the ability to benefit depends on the individual's income and the effectiveness of regulations. It is easier and more cost-effective to control product safety in a market chain when fewer farms are involved. Better-off urban consumers also appreciate the convenience of integrated dairy market chains and where market chains are well regulated they also appreciate the reassurance of certified products.

However, as discussed in the previous section, the benefits of integrated market chains take time and require good regulation to come into effect, and food that is certified as safe may not be affordable for the urban poor. Food safety requires investment by all market-chain stakeholders including producers, collectors, transporters and processors, who are not always rewarded with higher prices. In some countries foods that are labelled as safer or otherwise of higher quality can command a higher price; some consumers will not choose to benefit while others cannot afford to. Given the relatively slow rate of scaling up in the dairy sector, it is particularly important to ensure that equal attention is given to food-safety practices suitable for small and medium-sized enterprises so that levels of food safety are improved throughout the dairy sector, to the benefit of all involved.

All consumers can benefit from economies of scale if the market is large enough; in developed countries supermarkets have played a part in keeping milk prices down to the benefit of consumers, although not of farmers.

9.2.5 Local or global?

Chapter 2 describes dairy products as being far less traded internationally than meat, with only about 13 percent by volume being exported, representing 6 percent of agricultural export value compared with 10 percent for meat. The perishability of milk and regional preferences for certain dairy products contribute to the high proportion of milk and dairy products consumed within the countries of origin.

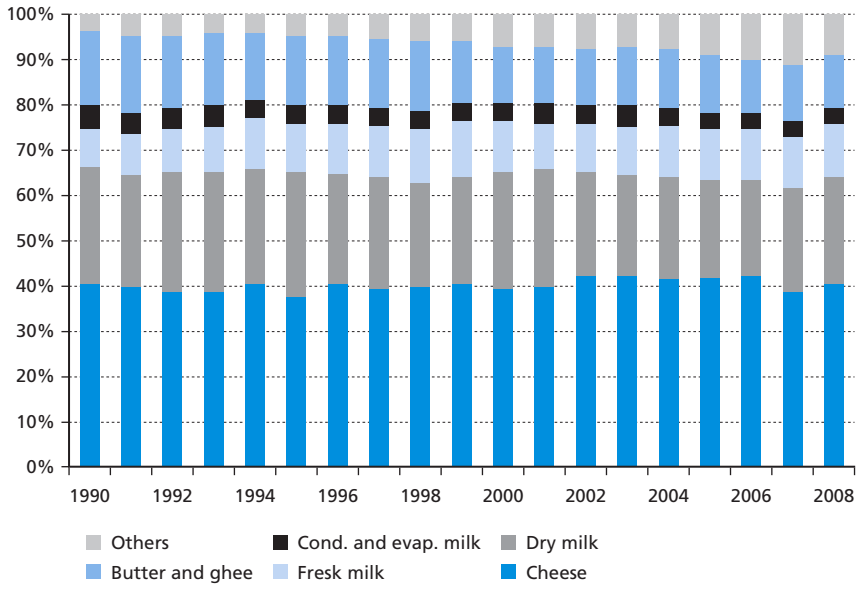
Chapters 2 and 8 point to local differences in species milked and the way in which milk is valued, consumed and processed by different cultures, and to great pride in national specialities. All of these factors suggest that dairying can be seen as a strongly local business, with most of the product consumed in a country being produced in that country.

To some extent the notion of localness is accurate. Locally produced dairy products are consumed in countries all over the world and, as Chapter 8 points out, public-sector funds have been invested with the goal of making Africa and Asia self-sufficient in milk. The catchy slogan "a glass of Asian milk a day for every Asian child" highlights the objectives of the Asian dairy-development strategy developed by senior regional stakeholders (Dugdill and Morgan, 2008). The Indian central and state governments have for many years financed smallholder dairy production through the National Dairy Development Board; since the liberalization of the market there has also been investment from India's domestic private sector, although more than 80 percent of milk is still sold through informal channels (Punjab, 2009). China, too, has used government investment to stimulate local private industry in Hebie and Heilongiang provinces and the autonomous region of Inner Mongolia (Chapter 8). In Africa a number of small dairy projects, many of them initiated by NGOs in support of small-scale production and marketing, have helped to supply local populations with dairy products.

Notwithstanding important local differences, however, dairying is a global industry in which several multinational companies have an interest. While most strongly represented in the developed countries, multinational companies have also invested in initiatives in South Asia and Africa with varying degrees of success, Nestlé's investment in Pakistan being one example. It is also the case that the overall level of foreign direct investment in dairying is low, as it is for agriculture as a whole (FAO, 2012b); multinationals have ventured into developing country markets with caution. Processed dairy products, in particular milk powder, infant formula and cheese, are widely traded. Not only did total world trade in dairy products increase from US$20 billion in 1990 to US$64 billion in 2008, but over the same period the value of trade per person increased from US$3.8 to US$8.4 (calculated from FAOSTAT data). Figure 9.1 shows the percentage share of each of the main internationally traded dairy products in total export value between 1990 and 2008. Cheese and dried milk made up the bulk of export value, followed by butter and ghee (albeit with the latter showing a declining market share). The majority of products came from cow milk. These traded products supply a wide range of markets, with the higher-value items going to wealthy consumers for direct consumption while milk powder and the cheaper cheeses supply the baking and fast-food industries.

World milk prices and milk imports affect the functioning of domestic markets in developing countries. As Chapter 2 points out, improvements in processing and shipping technology, reduction in transport costs and times and the use of export subsidies have promoted international trade in dairy products and encouraged its rise, although to a lower level than meat. The European Union, once strongly criticised for "dumping" milk powder on West African markets, has reduced its milk-powder stocks and lowered subsidies. However, imports do not have to be incompatible with domestic dairy-industry development – India and China both have growing domestic industries and both import dried milk from the developed world.

FIGURE 9.1
Percentage share of various dairy products in the total value of dairy exports, 1990 to 2008



9.2.6 Dairying and climate change

The dairy sector has a two-way relationship with the environment. On the one hand it is implicated in the production of greenhouse gases and contributes to climate change. On the other hand, dairy production is affected by the availability of natural resources and must adapt to climate change.

Greenhouse gas production, while important, is currently having limited impact on decisions about dairy-industry development because no economic instruments are being applied to carbon reduction in the dairy sector. Chapter 8 mentions the growing concern about the carbon footprint of all sectors, including agriculture. Ruminants produce higher levels of greenhouse gases within their life-cycles than poultry and pigs, but milk production produces less methane per unit of output than meat, and well-managed intensively kept dairy animals produce lower volumes of methane per unit of protein output than animals with a lower output (Henderson, Gerber and Opio, 2011). Small projects are exploring the use of biogas digesters to manage manure and improved management of rangelands and pastures to promote carbon sequestration as economically rewarding ways of offsetting the greenhouse gas from extensive livestock (Chapter 8; Lipper, Pingali and Zurek, 2006; Mooney, 2009). As Chapter 8 points out, there are valuable discussions and analyses taking place within the dairy sector and between international agencies on ways to reduce emissions in dairy market chains. However, agricultural emissions are not currently

part of emissions trading and no taxes are applied to greenhouse gas emissions from livestock, so these considerations are not currently affecting the location or intensity of dairy-industry development.

Climate change has the potential to change the location of dairy production. The optimum conditions for dairy cattle are those where the climate favours the growth of protein-rich grasses and supports the high-yielding dairy cattle bred for cool temperate regions with temperatures between 18 and 20 °C. Water is needed for milk production and also for processing. These factors favour concentration of milk production in certain areas, including the highlands of East Africa, the north of China, the grasslands of Argentina, Brazil and New Zealand and parts of Europe. As certain areas become hotter and drier, or as competition from biofuels raises the prices of inputs, production may relocate.

However, changes in location need not necessarily affect the contribution of dairying to human nutrition – production and consumption centres are already separated in much of the world. Most of China's milk is consumed in the south of the country while production is in the north, and much of East Africa's population lives on coast while the most productive dairy herds are in the highlands. As a result, there is already considerable movement of milk and other dairy products within the countries where it is produced, as well as the increasing exports of processed dairy products previously discussed.

9.2.7 "Nutrition-sensitive development": can dairying contribute?

Integrating nutrition and agricultural development seems intuitively obvious, but a discussion brief from the International Food Policy Research Institute argues that often this link is not made, with those who fund nutrition programmes preferring to invest in supplementation and food fortification (Levin *et al.*, 2003). By implication, agricultural development has become somewhat de-linked from explicit nutritional aims. A World Bank publication in 2007 threw out the challenge that "agricultural programs should … include nutrition as a specific objective and a clear plan of how to implement nutrition-sensitive agricultural interventions and how to achieve impact". The most prominent examples have come from small-scale crops, such as the integrated gardening programme in Bangladesh that involved 900 000 households and the promotion of orange-fleshed sweet potatoes in Mozambique (Arimond *et al.*, 2011). No similar examples exist for dairying. As noted elsewhere in this chapter, several dairy-development projects appear to have had beneficial impacts on nutrition, but for the most part they have set out to target income or production rather than nutrition.

Part of the reason for producing this book was to examine the possibility of rebuilding the links between dairy development and nutrition by making nutritional goals more prominent in dairy-industry development and other dairy programmes. In theory this might be achieved in either of two ways: by providing the ingredients for specially formulated supplementary or "blended" foods that use milk powder as an ingredient; or by using what are called "food-based" approaches to make dairy products more readily available to those whose diets are currently deficient in a range of essential nutrients and who would benefit from consuming milk and dairy products on a regular basis.

Food-based approaches include dietary diversification and modification (adding new elements into the diet, to boost its nutritional content or help the absorption of

micronutrients), biofortification (changing the composition of agricultural products through breeding or genetic modification – the high-betacarotene orange-fleshed sweet potato being one example) and fortification (adding micronutrients to food or putting them in processed foods, rather than giving supplements as a pill). Gibson (2011) argues that a combination of approaches is likely to be needed in developing countries. Dairy products provide a way to diversify the diet, and when consumed in moderate quantities can enhance the diet and improve nutrition.

Thompson (2011) suggests that using micronutrient-rich foods to create a balanced diet is a more sustainable way to improve nutrition than providing supplements. Milk can also be fortified by adding vitamin A or D or minerals such as iron. In some countries, for example Canada, fortification of milk with vitamin D is mandatory. A recent review (Girard *et al*., 2012) noted the necessity for promoting strategies that improve access and availability of supplements and fortified food concurrently with strategies to improve access to diverse foods.

Examining the list of dairy-industry development programmes described in Chapter 8, many have set out with the assumption that the result would be increased consumption of dairy products, and some have specifically targeted women or poor farmers, both seen to be in need of increased income and greater food security. However, few dairy-industry development programmes have started with the primary intention of improving nutrition in vulnerable groups (Chapter 8). Even dairy programmes in developing countries have not done enough to measure whether nutrition was improved (Chapter 7).

Dairying almost certainly could contribute more to nutrition-sensitive development, and food-based approaches would be likely to work best. However, as indicated in Chapter 8, this would require a change of focus in dairy programmes, in ways that are discussed in the following section. It would also require more evidence of the links between dairy programmes and nutrition, both to help in the design of nutrition-sensitive programmes and to justify the need for them. While there is growing knowledge and awareness of the nutritional and health benefits and risks of dairy products, Chapter 4 and Chapter 7 have highlighted the many knowledge gaps – the precise health impacts (good and bad) are not yet clear. There is also limited information on the economic value of dairy-based approaches to nutrition compared with those using other foods, both animal and plant source. However, it is clear that age, physiological status and even genetic factors have to be taken into consideration, and the fact that milk is a complex food containing numerous nutrients has to be kept in mind. The second half of this chapter explores the options for designing dairy development to more explicitly pursue nutrition objectives.

9.3 OPTIONS FOR NUTRITION-SENSITIVE DAIRY DEVELOPMENT

Dairy development is influenced by economic trends, government policies and private-sector investment. As discussed in Section 9.2, Key trends and emerging issues, the dairy sector is growing and projected to continue to do so. It contributes positively to human food security and nutrition and has the potential to contribute more. Dairying has played an important role in the livelihoods of small-scale producers, traders and retailers, particularly in Asia and Africa, with dairy supply chains slower to scale up and concentrate than those for most other

livestock commodities. At the same time, like other livestock sectors, dairy faces the challenges inherent in trying to provide a reliable and safe supply of food to an ever-growing and urbanizing human population while dealing with increasing pressure on natural resources and the environment. Development of the sector could be left to market forces or guided by planned government strategies and investment programmes. The most likely scenario is a combination of public and private intervention.

As discussed previously, dairy-industry development programmes have rarely set out with the explicit objective of raising the level of human nutrition; it is more common that they have the objective of increasing the milk supply and providing a livelihood to milk producers. Neither have commercial initiatives set out to raise nutrition levels – they have aimed at selling milk and securing a solid production base, with diversification into processed, probiotic and fortified products as a way of expanding market share in many cases. Some projects and investments have improved nutrition. Ownership of dairy animals in particular has been associated with improved nutritional status (Chapter 7). It is yet to be defined precisely who benefits most from dairy-industry development, or what types of development are best suited to raising the nutritional status of the most vulnerable groups.

If the emphasis shifted and dairy-industry development was expected or required to have a positive impact on nutrition, there would be implications for the way that programmes are designed and government policies, aid programmes and private investments are shaped. These are the subjects discussed in this section.

Much of what is said here is applicable within a wider food-security context and to any livestock product. New international initiatives are recognizing the need for coherence and collaboration (e.g. the Scaling Up Nutrition initiative [SUN, 2010] and the G8 New Alliance for Food Security and Nutrition). Nutrition-sensitive dairy-industry development is likely to be more effective if it is applied in an environment where there is high-level political commitment and improved nutrition is generally promoted, and where intersectoral collaboration is already the norm.

9.3.1 Measuring nutritional impact

One of the first things that may be needed to increase the nutritional impact of dairy-industry development, and that of other dairy programmes, is to measure more accurately what impact is already resulting from the expansion of dairy production. Casual observation suggests that programmes aimed at smallholder dairy production increase consumption as well as wealth in the families who take part in them, and that poor children who are beneficiaries of school milk programmes become better nourished and have better physical development. Yet Chapters 4 and 7 in this publication highlight the lack of systematic measurement and solid evidence, either positive or negative, of the impact of dairy programmes on consumption or dietary choices. Even less seems to have been published about the impact of private-sector investment on nutrition. The evidence linking dairy programmes and projects with health, although encouraging, is also inconclusive.

To improve the evidence base linking dairying and nutrition, the first task is to define the evidence that is needed to answer the following questions:

- As a result of the programme, project or initiative, do more people consume dairy products than before?

- Who is consuming more dairy products? Do they include vulnerable groups such as low-income families, children and pregnant or lactating women? Are there differences in consumption between rural and urban populations?
- How frequently do they consume dairy products and in what quantities? Is consumption in line with national dietary guidelines? Are dairy products consumed in sufficient quantities to effect nutritional change?
- Through what route did increased consumption arise: more consumption of home produce; more income spent on dairy products; a fall in the price or increase in availability of dairy products; dairy products provided to specific households or individuals? What influenced the decision to consume more?
- If the programme has increased family livelihoods, is there any evidence that this has contributed to dietary diversification in general and increased consumption of dairy products in particular?
- Is there any evidence that consuming additional dairy products or better dietary diversity resulting from higher incomes from dairy as a result of the programme has improved the growth and development or mental ability of children?
- Is there evidence that the programme has resulted in consumption of dairy products above recommended national dietary guidelines?

To answer these questions it may be necessary to measure changes in three things:

- consumption (quantities, frequencies and types) of dairy products
- dietary diversity
- improved or reduced nutritional status resulting from consumption of dairy products.

Measurement of nutritional status (though metrics such as body mass index, child growth and biochemical tests to measure micronutrient status, as described by FAO [2005]) is the hardest, takes longest and requires skills that may not be available among the agriculture specialists who run dairy projects. These skills can only be acquired through specialized training, and it is more effective for dairy programmes to link with nutrition and human-health programmes that are already measuring the variables of interest. In practice it is rare that randomized controlled trials, considered the gold standard for evaluation, are supported by funding agencies or can be afforded by implementing organisations (Girard *et al.*, 2012). However, it may not be necessary for every dairy programme to measure health impacts. A few additional credible studies linking dairy consumption with dietary intakes and nutritional outcomes would provide a sufficient base on which to draw conclusions from data about consumption.

Measurement of dietary diversity is simpler, but still requires detailed surveys at household or village level. Consumption of dairy products is the easiest factor to measure, provided that the programme can define the target population that it might reasonably be expected to affect. It is easy to locate the farmers who produce and consume milk and those who work for them, but harder to assess who in an urban population might have benefitted from having more milk produced. It is also important to design rigorous evaluations that take account of factors other than the dairy programme that may affect consumption; these might include a general increase in incomes or the opening up of additional livelihoods opportunities. Investment

in large programmes like that of India and the East Africa Dairy Development project funded by the Bill and Melinda Gates foundation (Chapter 8) provides an opportunity to include well-designed evaluation on the scale necessary to measure consumption impacts. Chapter 7 describes a few examples on which to build, such as the study by Alderman (1987) in India and that by Ayalew, Gebriel and Kassa (1999) in Ethiopia.

The following points also need to be taken into consideration:

- Dairy programmes that aim to improve nutrition should include evaluation of nutritional impact from the start and have it built into their design. Whether the programme is a private or a public investment, measuring impact requires a baseline.
- Programmes that aim to increase supplies to urban populations will have a more difficult measurement task since many consumers will be distant from producers and hard to locate. Much has been written about the nutritional value of livestock ownership (e.g. Randolph *et al.*, 2007), but far less has been written that directly links changes in production patterns with urban consumption.

9.3.2 Design of dairy programmes for nutritional outcomes

This section focuses on programmes and projects that are funded with the specific aim of improving nutritional impact. This means that it is likely to be applicable to publicly funded development efforts or those funded by the private sector that have a social as well as profit objective.

The first step in designing a programme is to determine its objectives and a dairy programme that aims to improve nutritional outcomes may have more than one objective. It may be aiming to boost the milk supply, support producers in a particular area and/or increase consumption of safe and nutritious food among the poor. These objectives can be harmonious but they can also conflict, making project design somewhat challenging. For example, a programme that increases milk supply and improves quality by investing in large-scale production and processing may unintentionally displace small-scale producers.

As discussed in Section 9.2.4, it is generally accepted that it is easier to provide an abundant, cheap and safe milk supply from fewer, larger farms than from numerous small farms, but this may not benefit large numbers of small-scale rural producer-consumers. Setting price ceilings that ensure cheap milk to cities discourages producers and encourages the development of parallel markets. Keeping food prices low through subsidies affects all consumers, not only a limited target group, and for that reason it can be an expensive way to promote consumption by poor consumers as well as encouraging overconsumption by others.

The difficulty of pursuing multiple objectives may explain why dairy-industry development programmes have not been strongly focussed on nutrition and why dairy-industry development and nutrition have tended to follow different paths in public investment. To bring them together is likely to require a comprehensive programme that contains elements of conventional dairy-industry development programmes and conventional nutrition programmes.

Any programme in the dairy sector is likely to work better in targeting nutrition if it is part of the wider nutrition strategy for the country; there may already be

nutrition or education initiatives with which it can work, and the long-term return on investment may be greater. This particularly applies to programmes where the main consumer group lives in urban areas. If there is no solid nutritional strategy on which to build, the dairy sector may need to lead the way.

Some practical considerations include the following:

- Nutrition impact assessment should be built into the programme design. This requires involving disciplines and institutions beyond agriculture to bring in the skills and mandate to measure nutritional indicators.
- Elements aimed at changing consumption patterns should also be built into the programme. Nutrition education is universally accepted to be important in changing food habits. Direct provision of food can also kick-start changes in diet. Processing that makes dairy products more appealing and convenient helps them to compete with less nutritious foods (such as carbonated soft drinks).
- Programmes must be realistic about the potential for improving nutrition from the domestic dairy industry. For instance, Chapter 8 lists a number of considerations for successful dairy-industry development, including the availability of a suitable feed and forage base. If consumption is growing rapidly and the dairy sector more slowly, imports may be necessary to meet consumer needs.

The usual considerations for development projects would also apply, including design that fits local needs and objectives, provides assurance of quality and builds sustainability. There may be conflicts between the wish to develop the domestic dairy industry, supporting the livelihood of domestic producers and processors, and the wish to make milk available at low prices (which may more easily be done from imports), or between an approach that is primarily food based through milk compared with one based on micronutrient or food supplements.

9.3.3 Options for governments

Government has a strong role to play in any dairy-industry development programme, particularly one that includes explicit nutritional objectives. Important aspects of the government's role include the following:

- Identification of national priorities. National needs in relation to consumption and nutrition, support to small-scale vs large-scale production, public vs private investment will all vary according to the country's stage of economic development, its natural and human resource base and the balance between rural and urban populations. These priorities can only be set by national governments, and greatly affect the scale and shape of investment in dairy and nutrition. Governments that choose to protect or support the domestic dairy industry may do so through investment in domestic supply chains, subsidies on inputs, taxes on imports or incentives to export. They may choose to support small-scale production and livelihoods, or to focus on "modernization" of the industry, which implies scaling up and concentration.
- Identifying national nutritional challenges, promoting measurement of nutritional status and providing dietary guidelines. If a strong national

nutrition strategy exists, this provides a framework onto which to add a dairy programme.
- Investing in basic infrastructure. Roads, electricity and water supplies limit the practical scope of a dairy programme.
- Providing policies, laws and regulations that support nutrition-sensitive dairy-industry development and the provision of safe milk and dairy products, alongside other nutrition-sensitive agricultural actions.
- Promoting collaboration between the government agencies responsible for livestock development and those responsible for human health and social welfare.
- Promoting investment from both public and private sectors in sustainable dairy-industry development programmes.

9.3.4 Options for development agencies

Development agencies work within the policy environment set by governments (although they may also influence it). For programmes on dairy-industry development and human nutrition, particular support may be needed in the following areas:
- Placing a strong focus on nutrition-sensitive dairy-industry development.
- Financing dairy programmes that have explicit nutritional objectives and target nutritionally vulnerable groups.
- Being prepared to support the additional investment and work needed to combine dairy-industry development with human-nutrition objectives, and to measure nutritional impact.
- Helping to convene health and agriculture ministries and health and agriculture development partners.
- Complementing private-sector investment.
- Investing in building an evidence base on the nutrition/health benefits/risks, sharing it with governments and bringing together governments to work together on dietary guidelines and dietary education.

9.3.5 Options for the private sector

The private sector had led the dairy sector in the developed world and is putting investment into developing countries. If dairy-industry development is to be linked more explicitly with human nutrition, the private sector has the potential to make a social contribution by:
- using its considerable advertising ability to campaign for healthy diets;
- using its market reach and infrastructure to put milk and dairy products that boost nutrition within reach of low-income populations; and
- including nutritional components and objectives in dairy-industry development programmes.

There are also market opportunities, notably in:
- meeting demand for milk and dairy products in developing and transitional countries;
- supplying fortified milk into new markets in growing economies; and
- providing milk-based products that offer an alternative to soft drinks.

9.3.6 Summing up

Adding nutrition objectives to dairy-industry development certainly introduces additional complications – new objectives, new measurements, potential conflicts, more complexity in programme design, time needed to confirm results. In an era when development investment is in short supply, dominated by emergency funding and crisis response, this is a challenge not to be taken lightly. But it is not an impossible task; some projects have already managed to combine crop or livestock production with nutrition. Some 870 million people continue to be chronically undernourished and a further billion are eating unbalanced diets, with all of the associated financial costs and diminution of human well-being. It makes no sense to act as if agriculture and nutrition were separate, and this means setting out to build programmes that explicitly link the two – as endorsed by the Zero Hunger Challenge by the Secretary General of the United Nations.

DISCLOSURE STATEMENT

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MILK AND DAIRY PRODUCTS IN HUMAN NUTRITION

Milk and dairy products are a vital source of nutrition for many people. They also present livelihood opportunities for farm families, processors and other stakeholders in dairy value chains. Consumers, industry and governments need up-to-date information on how milk and dairy products can contribute to human nutrition and how dairy-industry development can best contribute to increasing food security and alleviating poverty.

This publication is unique in drawing together information on nutrition, and dairy-industry development, providing a rich source of useful material on the role of dairy products in human nutrition and the way that investment in dairy-industry development has changed. The book draws together the threads of the two stories, on nutrition and on dairy-industry development, by considering key trends that emerge from the information presented and highlighting the issues that arise from them. It discusses the implications of these findings for the future of the dairy sector, particularly in developing countries.

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