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Understanding and improving the functional and nutritional properties of milk

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Introduction

Milk and dairy products have long been one of the major food groups in diets in many parts of the world, particularly since the domestication of cattle approximately 10,000 years ago. Current annual global milk production exceeds 850 billion kg, equating more than 100 kg of milk per person per day on average. Undoubtedly one of the most important reasons why milk and dairy products have become such an important food group in diets worldwide is the richness of nutrients. For example, in the Netherlands, milk and dairy products provide close to 60% of total dietary calcium, close to 40% of dietary vitamin B2 and B12, >30% of dietary retinol and phosphorus and >20% of dietary iodide, protein and zinc, while providing only 15% of total energy intake. Milk and dairy products also provide proportionally more potassium, selenium and magnesium than energy to the Dutch diet. High contributions of milk and dairy products to total nutrient intake are also found in many other counties, particularly in Europe, North America, Oceania and parts of the middle East and of Asia. In addition to the nutrient richness and other nutritional properties, the relative ease with which milk can be converted, with relative ease, into a wide variety of safe and shelf-stable products with favored sensory properties has further fueled development and growth of the dairy sector. In addition, milk and by-products of dairy production also can be used as the basis for ingredient manufacture for application in a wide range of dairy and non-dairy food products, but also non-food products, including pharmaceuticals and cosmetics.

Despite the aforementioned great role of milk and dairy products in many diets worldwide, the dairy sector also faces challenges, as does the whole food system. The growing world population leads to increasing demands for food worldwide, and many areas in the world still suffer from malnutrition. However, there is also an urgent need to address issues relating to the environmental sustainability of the food system to combat climate change. Key areas of concern in terms of the environmental impact of the food system include greenhouse gas emissions, land use and water use. A sustainable food system should provide healthy diets for the global population and do this within planetary boundaries. For milk and dairy products, as well as for any other food product, it is thus crucial that environmental impact is limited as much as possible and is justified by contributions to human nutrition and health. For milk and dairy products, this requires an in-depth understanding of compositional and nutritional properties, which can subsequently be applied to design strategies for further optimization.

Understanding and improving the nutritional properties of milk is thus of critical important basis for the role of milk and dairy products in sustainable food systems. In this book, we cover essential elements of this, which together can form an important basis for not only understanding the nutritional properties of milk and dairy products, but also for improving them. In Part 1, the importance of milk and dairy products in the human diet is covered in Chapter 1, and distinctly outlines the many important contributions of milk and dairy products to human nutrition and health. In addition, Chapter 1 also highlights that milk and dairy products should not be considered as simply a collection of nutrients, but that the way in which these nutrients interact in the product, i.e. the product matrix, is very important for the nutritional and health benefits of milk and dairy products. This importance of matrix effects is also clearly highlighted in Chapter 2, which focusses on understanding the digestion of milk proteins and fat. From this Chapter, it is clear that compositional variation is important for digestion, but the structural changes induced by processing, e.g. heating and homogenization, also strongly affect digestion of milk proteins and milk fat. In addition, interspecies variation can also strongly affect milk properties, including those to nutrition and health. While most milk consumed worldwide is bovine milk, particularly buffalo, caprine and ovine milk make important contributions to diets in different parts of the world. To illustrate the importance of this interspecies variation, Chapter 3 covers interspecies variation of milk properties and composition, both in terms of macronutrients and micronutrients.

Many technological and nutritional functionalities of milk and dairy products are related to the milk proteins and milk lipids, which are the focus of Part 2 of this book. The caseins are the most abundant class of milk proteins, and are the focus of Chapter 4. This chapter focusses on advances of understanding of caseins and casein micelles, covering recent insights into genetic variation and posttranslational modification, but also casein-salt interactions and their effect on casein micelle structure, stability and functionality. Next to caseins, the whey proteins also provide key functionalities in milk and dairy products, but also dairy ingredients. Physicochemical and technological properties of whey proteins are covered in Chapter 5, which highlights a wide variety of opportunities for functional whey protein ingredients. The nutritional properties of whey proteins and whey protein ingredients are covered in Chapter 6 and illustrate valuable applications in many areas, including infant nutrition, nutrition for patients recovering from operations or other medical treatments and to prevent sarcopenia. In addition, bioactive properties of whey proteins are also covered in Chapter 6. There are cases where bioactivity of whey proteins can be enhanced by enzymatic hydrolysis. The application is widely applied in the dairy industry and the various functional milk protein hydrolysates are covered in Chapter 7. Next to milk proteins, milk fat also has important functional properties. Technological functionality is often related to

fatty acid composition and stereospecificity of the fatty acids and their effect on crystallization behavior, which is covered in Chapter 8. Chapter 9 describes advances in the understanding of nutritional and bioactive properties of milk fat. A very important feature here is the organization of milk fat in the form of milk fat globules and the milk fat globule membrane on the surface of these milk fat globules.

Both nutritionally and functionally, proteins and lipids play an important role in milk and dairy products, but other constituents are equally important and are covered in Part 3 of this book. Chapter 10 covers the third macronutrient in milk, i.e. lactose. With comparatively limited current research attention to lactose and main focus often on lactose intolerance, important nutritional properties of lactose are at risk of being overlooked. For instances its low glycemic index and low cariogenic potential, which can be key contributors to human health. In addition, many other carbohydrates from milk or derived from lactose can have important nutritional benefits. These include for instance oligosaccharides but also glycans attached to proteins. The properties and benefits associated with these carbohydrates are covered in Chapter 11. Chapter 12 focusses on the enzymes in milk. Enzymatic processes in milk can affect nutritional quality, but also physical stability of milk and are thus always an important topic of consideration when looking at improving the properties of milk. Another key influencing factor for stability of milk and dairy products are the milk salts, which are the focus of Chapter 13. The milk salts often govern protein stability and are thus very important. Likewise, milk and dairy products are also a key source of e.g. calcium and phosphorus in many diets and this requires the salts to be bioavailable, which is also covered in Chapter 13.

The important role of milk and dairy products in many current diets, coupled with the necessity for more sustainable diets, drives much research towards optimizing milk composition and quality. Many key aspects of this are covered in Part 4 of this book. State-of-the-art instrumental techniques are a prerequisite for being able to monitor quality aspects of milk quickly, efficiently and accurately. The latest advances in these techniques, including e.g. infrared and nuclear magnetic resonance techniques are covered in Chapter 14. Such techniques are often at the basis of research into improving milk composition and quality. Such improvements may be achieved via either selection of animals based on genetics or via feed. Chapter 15 describes the opportunities for improving milk properties via genetic selection, either to improve gross composition or to improve functional or nutritional properties through selection of specific protein variants. Next to genetic selection, animal feed also is crucial in milk composition and offers opportunities to improve composition and nutritional properties of milk, which are covered in Chapter 16. Of course, improvements in milk composition and properties through genetics and feed become of true value when they can be applied in consumer products. This

requires the milk to be converted into safe, stable and sensorially desired dairy products. Sensory aspects of milk, both in terms of understanding and analysis are therefore covered in Chapter 17, whereas Chapter 18 covers microbial quality and spoilage of milk. Both these aspects are crucial to create products which are accepted and favored by consumers. These products can be in various formats, with three main classes of dairy products being liquid milk products, fermented dairy products and cheese. For each product class, the constituents of the milk, their interactions and their changes during the shelf-life of the products have notable and quite different effects on product texture and sensory perception thereof. For this reason, the final three chapters of this book cover the relationship between the different milk constituents and their interactions in relation to the textual properties of liquid milk products (Chapter 19), fermented dairy products (Chapter 20) and cheese (Chapter 21).

Overall, we believe that the wealth and knowledge and insights provided by the authors throughout all the chapters in this book clearly highlights the depth of understanding that is available on the nutritional properties of milk, and how all milk constituents, and their interactions, play a crucial role in this. In addition, to understanding, the chapters also provide clear paths to further improving our understanding, and pathways to apply the understanding to improve milk and dairy products further, e.g. via improved milk production strategies or via improved processing. This understanding and these improvements will undoubtedly further strengthen the importance of milk and dairy products in human diets worldwide.

Chapter 1

The role of the dairy matrix in the contribution of milk and dairy products to the human diet

Jan Geurts, FrieslandCampina, The Netherlands

1 Introduction
2 Dairy as part of a sustainable diet
3 The dairy matrix
4 Dairy matrix effects: case studies
5 Conclusion
6 Where to look for further information
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1 Introduction

Milk and dairy products are an important part of the daily diet in many regions of the world due to their recognized contribution to the recommended intake of a variety of valuable nutrients, the amount of energy (calories) provided compared to other basic food categories and the natural power to compensate for foods in the diet with lesser nutritional value, such as grains.[1–4] An example of the nutrient contribution of dairy products to a typical diet is presented in Fig. 1. In this figure, the mean contribution of dairy products and substitutes to the intake of nutrients in the Dutch diet is given. Dairy products represent one of the five core food groups in most dietary guidelines worldwide. Data extracted from the Food and Agriculture Organization (FAO) database on food-based dietary guidelines from 80 countries[5,6] shows that 59 countries provide specific recommendations for dairy intake: 56 countries give daily recommendations and 3 countries advice weekly intake of dairy (Dominican Republic, Guatemala and Honduras). The other 21 countries mention dairy in various ways in their statements. The United Kingdom recommends 'some' milk and dairy every day, Canada no longer has recommendations to consume a certain number of servings of milk products and there are no serving sizes mentioned in the Canadian National guidance documents either. The Russian Federation recommends 325 kg of milk and dairy/person/year. Colombia's

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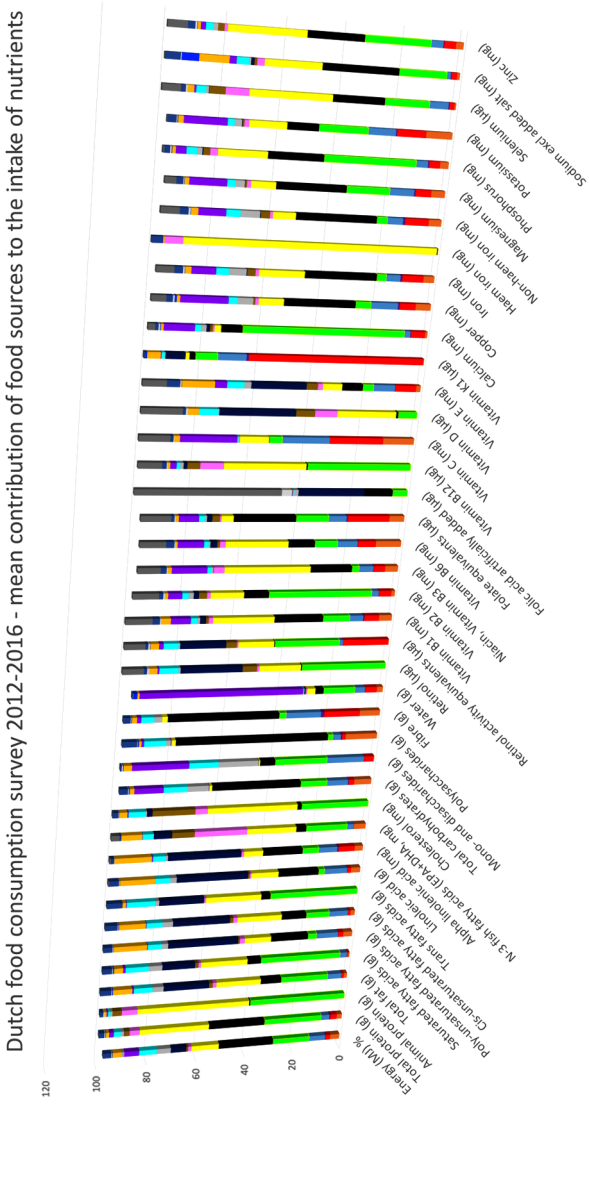

Figure 1 Mean contribution of food sources to the intake of nutrients in the Dutch diet. Source: food consumption survey 2012–2016 (VCP 2012–2016), National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands.

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