**Dairy in a sustainable diet: a question of balance**

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The demand for dairy products is growing rapidly, especially in emerging markets. Dairy products are nutrient rich and, therefore, an important food group for ensuring nutrient security in the future. In many countries, dairy contributes significantly to nutrient intake. Meta-analyses have shown that consumption of dairy may reduce the risk of chronic diseases and thereby lower healthcare costs. Milk production and processing contribute to greenhouse gas emissions, estimated at 2.7% (cradle-to-retail) of the world’s total. Evaluating the position of dairy in the diet should take into account the impact of both nutritional and environmental factors. Local conditions are also important; in many parts of the world, the cow is an efficient converter of human-inedible resources into nutrient-dense food. Increased productivity of cows is a decisive factor in realizing sufficient milk production with optimal resource efficiency and minimal greenhouse gas emission. Models that optimize total diets, rather than individual food products, for their nutritional and environmental impact are the preferred approach for developing realistic alternative consumption strategies.

**INTRODUCTION**

Supplying a growing population with sufficient food to meet energy and micronutrient needs is one of the world’s greatest challenges. It is estimated that world food demand will increase at an average rate of 1.1% per year between now and 2050. Most demand exists in emerging markets where there is fast population growth and a continuous rise in income. The Food and Agriculture Organization (FAO) concluded in its updated analysis of 2012 that the challenge to realizing food security is determined more by socioeconomic and local-specific factors than by the capacity of the world to produce sufficient food. However, many food-insecure countries, especially in sub-Saharan Africa, will still exist with an estimated undernourished population of more than 300 million people by the year 2050. At the same time, overconsumption of calories will dramatically increase the incidence of obesity (>50% of UK adults by 2050), with detrimental effects on health. Food consumption projections indicate that in all parts of the world, the per capita consumption of commodities will increase, as shown in Figure 1.

Animal products play an important and growing role in diets worldwide, supplying, on average, 17% of the energy and 35% of the protein. Animal products are nutrient rich and provide many highly bioavailable essential nutrients, which are especially important in the diets of children, pregnant and lactating women, and the elderly. Even small amounts of meat and dairy products can improve the nutritional status of those living in low-income households. The estimated global demand for raw milk will increase from the current 704 million tons to 1077 million tons by 2050. Because milk consumption in developed countries has stabilized, the 50% volume growth will mainly be due to increased consumption in developing countries. This will require significant structural changes in the dairy supply chain, especially in countries where consumption will increase. The world dairy sector is characterized by a high degree
of diversity in all parts of the chain. Farms range in size from 1 to 5 cows in many developing countries to more than 200 cows per farm in New Zealand. According to the International Farm Comparison Network, close to 1 billion people in the world live on dairy farms and the worldwide average is 3 or fewer cows per farm. Cows are efficient converters of human-inedible feed and by-products from feed and food chains into nutrient-rich milk, something that is especially relevant to small farms (see the Energy and Protein Efficiency section below). Also, the yearly milk production per cow shows a large variation—from 2539 kg/cow in China to 9682 kg/cow in the United States. Since important environmental issues such as resource efficiency (feed, water) and greenhouse gas (GHG) emissions are strongly dependent on the milk yield per cow, there is significant potential to increase the volume of milk that will result in improved resource efficiency and reduced GHG emissions (see the Dairy and Sustainability section below). There is also large variation on the consumption side of the equation. The yearly average milk consumption per capita varies from 52 kg/person/year in developing countries to 202 kg/person/year in developed countries, although that difference is expected to decrease. While dairy contributes substantially to nutrient security, the sector has been criticized for its environmental impact. The future position of dairy in the diet should, therefore, be based on a balanced analysis of nutritional and environmental aspects. This article discusses these aspects of the dairy sector in more detail.

CONTRIBUTION OF DAIRY TO THE DIET

Intake of nutrients

Milk products are considered a basic food group in many diets. It is a nutrient-rich beverage, and consumption of dairy products is associated with better overall diet quality. Therefore, dairy is a core part of dietary recommendations around the world, and many countries recommend 3 or more dairy servings per day in their dietary guidelines. The 2010 Dietary Guidelines Advisory Committee in the United States concluded that 3 servings of dairy per day would contribute proportionally more protein, calcium, magnesium, phosphorus, potassium, zinc, selenium, vitamin A, vitamin B₂, vitamin B₁₂, and choline than calories to the food pattern. In developed countries, especially, dairy products contribute significantly to the intake of essential nutrients and protein.

Table 1 and Figure 2 provide an overview of the intake of selected nutrients in the Dutch and US populations relative to the European recommended daily allowances and US dietary reference intakes, respectively. Table 1 shows the contribution of dairy to the intake of these nutrients. It is clear that intakes of folic acid and vitamin D are below recommended levels. Although vitamin D can be synthesized in the skin when directly exposed to the sun, most people meet at least some of their vitamin D requirement through endogenous synthesis. However, numerous public health agencies recommend limiting exposure of skin to sunlight in order to lower the risk for skin cancer. The Dutch population consumes more dairy than the US population; thus, dairy intake makes a larger contribution to nutrient intakes in the Netherlands. Two clear exceptions are vitamins A and D, which are supplemented in US dairy products, making dairy an important source of these nutrients in the United States. In many developing countries, the intake of milk is increasing but is unlikely to increase to the levels found in developed countries due to differences in dietary patterns. Governmental programs to increase consumption of dairy in developing countries typically target the most vulnerable groups, such as children and lactating women, for whom dairy products are an important

Figure 1 Food consumption per capita, major commodities (kg/person/year).
source of nutrients. Although people with lactase non-persistence can tolerate moderate amounts of milk (e.g., 250 mL), the existence of lactase nonpersistence together with the frequent occurrence of perceived lactose intolerance will always be factors that limit milk consumption, despite the fact that the number of lactose-reduced and lactose-free dairy products is increasing.

Nutritional contribution and carbon dioxide footprint of milk compared with other beverages

The average person needs about 750 L of liquid per year. Milk has always been a significant contributor to the beverage category. However, over the years, milk has been replaced by soft drinks, especially in the Western diet (Figure 3), resulting in milk consumption that is below recommendations in almost all developed countries. Compared with milk, soft drinks are often nutrient poor, contributing only sugar-based energy to the diet.

It is sometimes recommended that plant-based beverages replace milk because of the lower carbon dioxide footprint. In absolute terms, this might be true; however, relative to the nutrient content, the picture is different, as Smedman et al. showed. They assessed the contribution of several beverages to nutrient intake in relation to their carbon dioxide footprints. The conclusion was that the ratio of nutrient density to the carbon dioxide footprint was higher for milk than for beverages such as orange juice and unfortified soy beverages. It would be interesting to calculate this ratio for fortified plant-based protein beverages that have nutrient densities that are closer to that of milk.

Affordability of dairy nutrients

Dietary guidelines for nutrient intake can be effective only when consumer behavior can be changed. Important factors for consumer acceptance are that the foods that provide nutrients are appealing as well as affordable. To determine the most affordable way to consume required nutrients, the price per unit nutrient can be calculated for different food products. Figure 4 provides an overview of the price for consuming 10% of the recommended intake for several nutrients in the United States from vegetables, meat, or milk. These data clearly show that milk is a relatively cheap source of several essential nutrients, which is especially important in developing countries where nutrient shortages still exist.

Contribution of dairy to the intake of essential amino acids

In addition to the contribution of dairy to micronutrient intake, dairy is also an important source of high-quality proteins. In the Dutch diet, dairy products contribute 25% of the total daily protein intake, while contributing only 15% of the total daily calorie intake. Dairy protein is rich in essential amino acids and is highly digestible. In the battle for food security,
dietary protein will be the decisive component. It is, therefore, important to take protein quality into account when analyzing the nutrient adequacy of diets. The essential amino acid content, not simply the total amount of protein, should, therefore, be the basis when evaluating diets. Amino acid complementarity of proteins in a diet is important and is evident only by looking at the contribution of the essential amino acids provided by different proteins. High-quality proteins such as animal proteins can balance the amino acid pattern profiles of vegetable proteins in a mixed diet. An example is the combination of milk and wheat, in which the relatively high lysine concentration of milk proteins compensates for the low concentration of this essential amino acid in wheat.

Dairy and diet-related noncommunicable diseases

Currently, 63% of deaths worldwide are attributable to chronic disease and the number is expected rise to 72% by 2020; 80% of such deaths presently occur in low- and middle-income countries. Nutrition is seen as an important way to reduce diet-related noncommunicable diseases. Since full-fat dairy products contain saturated fat and saturated fat can lead to increased plasma cholesterol levels, which are associated with increased cardiovascular disease (CVD) risk, most dietary guidelines recommend consumption of low-fat dairy products. However, evidence of a link between dietary consumption (including full-fat products) and CVD from observational studies shows a neutral or even modest beneficial effect. Kratz et al. concluded that the observational evidence does not support the hypothesis that dairy fat or high-fat dairy products contribute to obesity or cardiometabolic risk and suggest that high-fat dairy consumption, within typical dietary patterns, is inversely associated with obesity risk. The recent debates in the scientific literature on this controversy have not produced a conclusion on the relationship between full-fat dairy consumption and CVD.

Prevention of chronic diseases with nutrition occurs via the intake of sufficient essential nutrients. However, nutrients do not work in isolation, and beneficial health effects will not result if the intake of 1 or more nutrients is suboptimal. Bone health is a good example of disease reduction that depends on the adequate status of several essential nutrients including protein, calcium, phosphorus, and vitamin D, all of which are found in dairy products. Overall, the results of meta-analyses provide evidence for a protective effect of dairy intake on chronic disease, which is also suggested in the overall survival advantage associated with dairy intake.

DAIRY AND SUSTAINABILITY

For the global dairy sector, GHG emissions and resource efficiency are 2 major sustainability issues that play roles on a global scale. Other factors such as water use and eutrophication are also important but are more local and will, therefore, not be discussed here.

Greenhouse gas emissions

In 2006, the FAO published the report *Livestock’s Long Shadow*, with the conclusion that 18% of the GHG emissions in the world are caused by livestock. This report not only brought a high level of awareness to the subject but also generated serious pressure on the livestock sector from politicians and nongovernmental organizations to develop new knowledge, support the public debate on global warming, and guide mitigation strategies. Because the private dairy sector, represented by the International Dairy Federation, needed more objective information to identify effective mitigation strategies, it supported the FAO in a systematic investigation of worldwide GHG emissions from the dairy sector. In 2010, the FAO finalized this study and concluded that the total contribution to global warming from milk production was 2.7% (cradle to retail), which amounts to an average of 2.4 kg carbon dioxide-eq/kg liquid milk. There is, however, considerable regional variation due to differences in farming systems, with GHG emissions ranging from 1 to 7.5 kg carbon dioxide-eq/kg milk. In the Netherlands, which has an intensive mixed farming system, i.e., the practice of combining agriculture and raising livestock, the contribution is 1.4 kg carbon dioxide-eq/kg milk. If dairy cattle–related meat production (slaughtered dairy cows and surplus fattened calves) is included, the total sector contribution increases to 4.0%. Methane has the largest global warming effect, responsible for 52% of GHG emissions, followed by nitrous oxide (35%) and carbon dioxide (13%). The cradle-to-farm-gate contribution is about 80% of the total emissions from the dairy chain.
suggesting that mitigation initiatives are likely to be most effective on the farm. The post-farm GHG contribution is related to fossil energy use and waste.

Energy and protein efficiency

Land use and methane emissions are highly dependent on the productivity of individual cows. For highly productive cows, more ingested energy is used for milk production relative to the maintenance requirements. The same is true for ingested protein. For example, increasing yield from 6000 to 10 000 kg/cow/year reduces the energy input per kilogram of milk by almost 20%.30 Because methane production is directly related to feed intake, the total GHG emissions per kilogram of milk will also decrease. Models predict that if the yearly yield of a cow increases from 2000 to 9000 kg, the GHG emissions decrease from 2.4 to 1.4 kg carbon dioxide-eq/kg milk.30 Another aspect of the discussion regarding the contribution of dairy to nutrient security is the degree to which cow feed directly competes with human edible food crops. Figure 5 shows the conversion efficiency of an average Dutch cow fed a mixture of roughage (72%), concentrate (25%), and wet byproducts (3%).

Dairy cows’ rations consist, for the most part, of resources that humans cannot or do not consume.31 These resources include not only grass and other cell wall–rich crops but also byproducts from feed and food chains. Because only a small fraction of the feed is edible by humans, ruminants only marginally compete with the human food resources. In fact, they convert human-inedible resources into high-quality human food. Although the efficiency of total input may not be greater than 22% and 27% for energy and protein (nitrogen), respectively, in the Netherlands, the return as edible food for humans is very efficient—357% for energy and 438% for protein. In countries with less intensive farming systems, the return on human-edible energy and protein is even greater due to the low input of concentrate in the feed.3 In addition, the cow converts lower-quality proteins such as grain and soy protein into proteins of the highest quality, based on the protein-digestibility–corrected amino acid score.32 The question of which food production system offers the most efficient and effective use of land strongly depends on local conditions and available infrastructure, but such an analysis is outside the scope of this article.

Mitigation strategies

An agenda for action is urgently needed to fulfill dairy’s role in establishing nutrient security while maintaining a responsible socioeconomic and environmental position. For this reason, the dairy sector has launched the worldwide initiative, the Global Dairy Agenda for Action. The purpose is to create a high level of awareness among all stakeholders and to initiate a series of actions devoted to mitigating dairy’s environmental impact.33 Given the expected growth in the milk supply, promising effective mitigation strategies include the following. 1) Increase the milk supply by increasing the productivity of cows. As discussed previously, an increase from 704 to 1077 million tons of milk by 2050 could theoretically be obtained by fewer cows with greater productivity, which could potentially reduce the average GHG emissions per kilogram of milk by more than 40%. 2) Reduce the number of cows by extending the number of lactations per cow. In practice, this means a reduced culling rate through improved animal health (less mastitis and hoof problems and higher fertility). 3) Use the potential energy from manure (Figure 4). In theory, the amount of biomass energy present in manure can replace a significant amount of the fossil energy consumed in the dairy chain, although this can only be done in confined farming systems. In the Dutch case, for instance, it would be possible to replace one-third (18 PJ) of the fossil energy used, partly by capturing the energy from the manure of the country’s 1.4 million dairy cows.34 Improved technologies are needed to capture the potential energy of manure in an economically feasible way. Furthermore, when it becomes economically feasible, the on-farm production of solar energy will be a huge potential energy source. 5) Improve manure and fertilizer management in order to reduce the soil nitrous oxide. Although the emission of nitrous oxide is not as unique to dairy farming as methane is, it still contributes a substantial amount to the dairy’s total GHG emissions. Effective reductions can be achieved by nitrification inhibitors.5 6) Reduce losses and waste. The FAO concluded that roughly 20% of milk for human consumption is lost or wasted globally, suggesting that considerable resources are used in vain and that GHG emissions are emitted without any yield.36 Although part of these losses and wastes are recycled through animal feed, there is a sufficient potential to reduce the environmental impact of the dairy sector by taking preventive measures. In developed countries, most of the wastes are at the consumer level, whereas in developing countries, it is mainly at the production level.36

Multidimensional optimization of total diets

Food security means first ensuring adequate diets for all people, now and in the future. “Adequate” in this sense means that the diet fulfills all the nutrient and energy requirements for healthy growth and aging. Basic foods
such as animal products (dairy, meat, fish), grain products (bread, rice, pasta), and vegetables and fruits are the most important contributors to nutrients and energy intake. On average, all people have roughly the same requirements for nutrients and energy, but the means by which they are delivered through the diet may depend on the geographic region of residence, socioeconomic status, age, activity profile, and individual preferences. Moreover, such diets should be based on production systems that minimize the environmental impact (including low emissions, no pollution, and minimal impact on biodiversity). Finally, such diets should be acceptable, affordable, and safe. The science of evaluating diets based on all these dimensions is still in its infancy, but some first attempts have been made. Macdiarmid et al. recently published a good example of this. The authors mathematically modeled a diet with respect to nutrient adequacy and minimal GHG emissions through a linear programming technique. They found that a reduction of 36% in GHG emissions could be achieved by optimizing existing food groups in a typical UK diet, while still maintaining the recommended nutrient intake. To guarantee a realistic outcome, acceptability and affordability constraints were added to the model. Due to the favorable nutrient profile of dairy, only a very small reduction in dairy consumption resulted from these model calculations.

**CONCLUSION**

The increased demand for dairy products needs to be realized, with the highest contribution to nutrient security and with improved resource efficiency and reduced GHG emissions. Infrastructural changes in milk production will be required to increase the volume of milk by as much as the predicted 50%. An increase in the productivity of dairy cows is crucial to obtain the required milk supply with minimal impact on scarce resources and global warming. When evaluating the position of dairy in a given diet, local aspects with respect to resource efficiency, as well as other environmental parameters, should be taken into account. Ruminants are excellent converters of human-inedible resources into high-quality foods that do not require sophisticated extraction technologies. This is especially true in developing countries. Infrastructural changes and new technologies are needed to mitigate the environmental impact of the dairy sector. Capturing the potential energy from manure together with the on-farm production of solar energy could significantly reduce fossil energy use by the dairy production chain. The modeling of diets with respect to nutrient adequacy and minimal environmental impact is a promising tool that refocuses the attention from comparing food products in isolation to evaluating complete diets. Modeling should also take into account affordability, food safety, and taste.

**Acknowledgments**

The authors thank Jan Dijkstra from the Department of Animal Nutrition of Wageningen University for his data input for this paper. The content of this article was presented as part of the Second Global Summit on the Health Benefits of Yogurt, held as a satellite to the...
Experimental Biology meeting in San Diego, California, on 30 April 2014. The conference was organized by the American Society for Nutrition and Danone Institute International. The supplement coordinators are Sharon M. Donovan, University of Illinois at Urbana-Champaign, USA, and Raanan Shamir, Schneider Children’s Medical Center, Israel.

**Funding.** Writing and editorial assistance were provided by Denisie Webb, PhD, RD, who was contracted and funded by Danone Institute International. Dr van Hooijdonk received financial reimbursement for travel expenses and an honorarium from the Danone Institute International for his participation in the conference.

**Declaration of interest.** The authors have no relevant interests to declare.

**REFERENCES**