Journal of the
Academy of Nutrition
and Dietetics

The premier source for the practice and science of food, nutrition, and dietetics

July 2013
ISSN 2212-2672

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Dairy Products: How They Fit in Nutritionally Adequate Diets

Edouard Clerfeuille, MSc; Matthieu Maillot, PhD; Eric O. Verger, MSc; Anne Lluch, PhD; Nicole Darmon, PhD; Nathalie Rolf-Pedersen, PhD

ABSTRACT

Individual diet modeling with linear programming recently provided evidence that plant-based products, fish, and fresh dairy products consumption should be increased in the French population to reach nutrient-based recommendations. The aim of our study was to estimate the number of portions of the different milk-based food categories fitting into nutritionally adequate diets. Starting from the diet observed for each adult in the 1999 French Enquête Individuelle et Nationale sur les Consommations Alimentaires survey (n=1,171), an isocaloric nutritionally adequate diet was modeled that simultaneously met a whole set of nutrient constraints (based on nutrient recommendations) while deviating the least from the observed diet food content. Variations in weight, energy, and nutrients between observed and modeled diets were calculated for each food group (n=7), with a focus on milk-based products (n=4 categories). The diet optimization process increased the weights of three food groups: fruit and vegetables (+62%), starchy foods (+37%), and dairy products (+19%). Across milk-based food categories, the optimization increased yogurts (+60%) and milk (+17%) and decreased cheeses (−48%) without change to milk desserts. Cheeses represented one out of two consumed portions of milk-based products in observed diets, whereas in modeled diets cheeses, milk, and yogurts each represented about one portion per day. Milk desserts were similar before and after optimization, at approximately one portion per week. These results confirm that a large increase in intake of plant-based products is needed. They show that rebalancing the intake of milk-based products in favor of the least energy-dense ones (ie, yogurts and milk) will help individuals in this population reach nutritional adequacy.
J Acad Nutr Diet. 2013;113:950-956.

THE WORLD HEALTH ORGANIZATION, IN ITS GLOBAL strategy on diet, physical activity, and health, recommends limiting the intakes of four nutrients to improve the population's nutritional status: saturated fatty acids, *trans*-fatty acids, free sugars, and sodium.[1] Food-based dietary guidelines (FBDG) are designed to help consumers make better food choices to cover their nutrient needs while limiting intake of nutrients of concern. These guidelines should be focused on local public health priorities, and have to be realistic according to the social, economic, and cultural context.[2,3] They are generally built upon expertise,[2] and sometimes quantitative approaches have also been used, such as identifying healthy food patterns and using them as a reference[4,5] or testing various combinations of food composites until finding a nutritionally adequate one.[6,7]

Linear programming is a unique tool allowing the systematic translation of nutrient-based recommendations into food combinations.[8] It is recognized as a robust approach to answer complex questions in human nutrition, such as identification of complementary feeding for preventing severe malnutrition in children,[9] identification of the way to reach nutritional adequacy at a low cost[10] with a low environmental impact,[11] or while controlling for exposure to chemical con-

taminants.[12] To rigorously design FBDG, it has been proposed to use diet modeling with linear programming.[13] A more sophisticated version of this method, called individual diet modeling, was recently developed[14] to better take into account the high variability of individual food patterns, thereby increasing the social acceptability of the modeled diets. Individual diet modeling is used to design, for each observed diet in a population, an isocaloric modeled diet that is not only nutritionally adequate, but also the closest, in terms of food content, to the corresponding observed diet. This approach, applied to French data, provided evidence of the need to increase total diet weight (and to decrease energy density) to achieve a full set of nutrient-based recommendations. These results were in agreement with general dietary guidance. More specifically, the greatest increases were seen for unsalted nuts, followed by unrefined grains, legumes, fruit, fish and shellfish, vegetables, and then fresh dairy products.[15]

The ideal types and optimal levels of foods needed to achieve national nutrient intake recommendations are an area of considerable research interest. The case of dairy products is particularly complex to address because they are both providers of the four nutrients to limit and providers of beneficial nutrients like vitamins and minerals, especially cal-

cium.[16,17] Moreover, the heterogeneity of milk-based products in terms of nutrient composition[18] begs the question of which milk-based products should be advocated and in what quantities. The French FBDG support the consumption of three dairy products per day, and advocate lower-fat varieties, such as milk and yogurt.[19] However, such recommendations were based on a national expert consultation that did not involve quantitative and reproducible modeling analysis.

Therefore, the aim of the present study was to estimate the optimal number of portions of the different milk-based food categories in nutritionally adequate diets, using optimized individual diets previously modeled from a representative dietary survey in the French adult population.[15]

METHODS

Dietary Data

The dietary data used in our study were derived from the 7-day food records of adults (n=1,171; age >18 years) of the Enquête Individuelle et Nationale sur les Consommations Alimentaires (INCA 1) cross-sectional dietary survey conducted in 1999.[20] A previously developed food composition database was used for this survey.[18] Alcoholic beverages, tea, coffee, and drinking water were excluded from the analyses because their consumption is often not well reported in dietary surveys. In addition, they are generally not considered food sources of essential nutrients in the recommendations. All foods in the database were aggregated into seven groups and 40 categories based on the INCA study classification[20] and the French FBDG.[19] Considering their nutrient composition and the way they are consumed, milk-based products have been split into four food categories belonging to two food groups. Specifically, the milk (eg, nonfat, reduced fat, whole, plain, and flavored), yogurts (eg, nonfat, reduced fat, full-fat, plain, flavored, and with fruits; French fromage-blanc is considered as a yogurt-like product) and cheeses (eg, hard, soft, cottage, and processed) categories were collapsed into the dairy products group, because their consumption is promoted by the French FBDG. In contrast, it is advised to limit the consumption of sweet products even when they contain milk. Thus, foods such as creamy desserts and rice puddings were included in the milk desserts category, the latter being one of the categories allocated to the sweets and savory products food group. Our study was focused on four milk-based food categories: milk, yogurts, cheeses, and milk desserts.

Following the French FBDG, oils and butter were collapsed into the added fats group; fruit, vegetables, and nuts were collapsed into the fruit and vegetables group; and potatoes, legumes, and cereals were collapsed into the starches and grains group.

Individual Diet Modeling

The aim of individual diet modeling is to design, for each individual in a population, an optimized diet that is both individual-specific and nutritionally adequate. Each optimized diet is obtained by changing as little as possible the food content of the corresponding observed diet to respect nutrient-based recommendations.

As previously described,[15] an optimization model called the BASAL model was applied to each of the 1,171 observed diets, leading to 1,171 nutritionally adequate modeled diets. In this

Table 1. Number of observed (n=1,171) and modeled (n=1,171) French adult diets containing each food group and each food category

Food group	Food Category	
	Observed	Modeled
Fruit and vegetables	1,166	1,171
Starches and grains	1,171	1,171
Mixed dishes and snacks	1,141	1,075
Meat, fish, poultry, and eggs	1,171	1,171
Added fats	1,171	1,171
Dairy products	1,166	1,171
Milk	793	883
Yogurts	911	932
Cheeses	1,102	1,064
Sweets and savory products	1,167	1,169
Milk desserts	467	444
Biscuits	492	468
Soft drinks	456	434
Desserts	989	1,021
Sweets	1,112	1,116
Pastries	542	454
Savory products	443	429

model, the optimization equation (also called the objective function) was aimed at preferentially choosing foods already declared as consumed by each individual, minimizing the reduction of foods already consumed, and introducing (only if necessary for the fulfillment of the constraints and in the lowest quantity possible) foods that were not declared as consumed by the individual. For these new foods, the model was designed to preferentially select the foods most frequently eaten by the studied population.

For each INCA study participant, the optimization process started from his or her observed diet (ie, 7-day food record and nutrient intakes) to design a new weekly modeled diet that was the closest to his or her usual eating pattern and that simultaneously met a whole set of constraints on nutrients. As previously described,[15] each modeled diet was isocaloric to its corresponding observed diet and the nutritional adequacy of the modeled diets was ensured by a set of constraints on proteins, lipids, carbohydrates, fiber, essential fatty acids, 10 vitamins, nine minerals, sodium, saturated fatty acids, cholesterol, and free sugars. In particular, we used the range 20% to 35% of energy from total fat, and a maximum of 10% of energy from saturated fatty acids and 10% of energy from free sugars as constraints on macronutrients. According to the World Health Organization, free sugars were defined as all monosaccharides and disaccharides added to foods, plus sugars naturally present in honey, syrups, and fruit juices.[1]

Constraints on food quantities were also introduced to ensure realism in the modeled diets. An upper limit, based on

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Table 2. Food groups and food categories (in g/wk and kcal/wk) in observed (n=1,171) and modeled (n=1,171) diets of French adults

Food group	Weight (g/wk)		Energy (kcal/wk)	
	Observed	Modeled	Observed	Modeled
	mean±standard deviation			
Fruit and vegetables	2,345.1±1,370.3	3,801.6±1,141.8*	1,000.2±683.0	2,231.0±920.5*
Starches and grains	1,776.3±802.8	2,439.2±668.1*	3,398.6±1,752.2	4,456.3±1,235.8*
Mixed dishes and snacks	1,364.5±972.8	574.1±512.6*	1,570.0±1,132.4	759.9±648.6*
Meat, fish, poultry, and eggs	1,402.4±565.7	1,235.9±344.2*	2,648.6±1,168.3	2,057.7±677.2*
Added fats	219.0±106.8	151.0±81.9*	1,453.5±695.7	985.1±547.4*
Dairy products	1,632.7±1,079.4	1,939.6±874.9*	1,660.4±892.5	1,434.7±448.7*
Milk	831.8±916.2	972.9±914.3*	378.1±417.0	439.7±412.7*
Yogurts	508.1±521.0	815.9±629.4*	339.6±365.8	492.0±392.1*
Cheeses	292.8±231.0	150.8±104.8*	942.7±748.0	503.0±352.0*
Sweets and savory products	1,216.4±1,020.3	1,030.6±665.9*	2,824.4±1,773.2	2,627.1±1,553.9*
Milk desserts	124.3±222.0	116.0±204.0	169.3±303.3	157.1±280.1
Biscuits	56.3±121.1	53.9±114.0	239.8±516.2	231.6±493.4
Soft drinks	278.9±761.8	185.4±420.6*	112.8±310.4	73.9±165.9*
Desserts	369.9±359.8	328.5±273.1*	880.2±848.4	913.6±809.4
Sweets	240.8±208.4	235.9±168.4	865.4±718.4	811.2±545.1*
Pastries	121.2±230.0	87.7±198.3*	454.0±851.7	339.0±783.1*
Savory products	25.1±62.5	23.2±47.9	103.0±250.6	100.7±209.1

*Significantly different from observed ($P<0.05$).

the observed distribution of food intakes in the population, was set for the quantity of each particular food, each food category, and each food group.

The modeled diets contained the same amount of energy as the corresponding observed ones, and their weights could not exceed 115% of their corresponding observed weights, to allow a decrease in the energy density of the modeled diets.

Effect of the Optimization Process

Presence, Weights, and Energy Contribution of Food Groups and Food Categories in Observed and Modeled Diets. During the optimization process, foods could have been added, or completely removed, to reach a nutritionally adequate diet. According to this, the number of diets containing a given food group or food category may have changed, and that number was therefore counted. In addition, the number of diets containing none, one, two, three, or four of the different milk-based food categories was computed.

To obtain a nutritionally adequate diet, the optimization process could increase or decrease the amount of each food in each diet. Therefore, the weight and the energy provided by each food group and each food category were calculated for each diet and the means between the 1,171 observed and the 1,171 modeled diets were compared using a pairwise Student *t* test.

Balance between the Four Milk-Based Food Categories in Observed and Modeled Diets. To assess the balance between milk-based food categories on a common basis, their weights were expressed as portions. Because no standard Reference Amount Customarily Consumed exists in France, recommended portion sizes from both the French FBDG and official recommendations for school cafeteria and hospital catering[19,21] were used. The portion sizes were set at 200 g for milks, 125 g for yogurts, 30 g for cheeses, and 100 g for milk desserts.

The number of portions per week provided by each milk-based category was calculated for each diet, and the means for the 1,171 observed and the corresponding 1,171 modeled diets were compared using a pairwise Student *t* test.

Variation in Nutrient Content between Observed and Modeled Diets. Nutritional adequacy of the modeled diets was ensured by constraints on nutrients. The content of nutrients relevant to milk-based products was calculated for each diet, and the differences in nutrients supplied by each food group and each food category before (observed diets) and after (modeled diets) optimization were calculated and compared with zero using a Student *t* test.

The Operational Research package of SAS (version 9.2, 2008, SAS Institute Inc) was used to run a linear programming model, and JMP (version 6, 2005, SAS Institute Inc) was used to perform statistical analyses. An α level of 5% was used for all statistical tests.
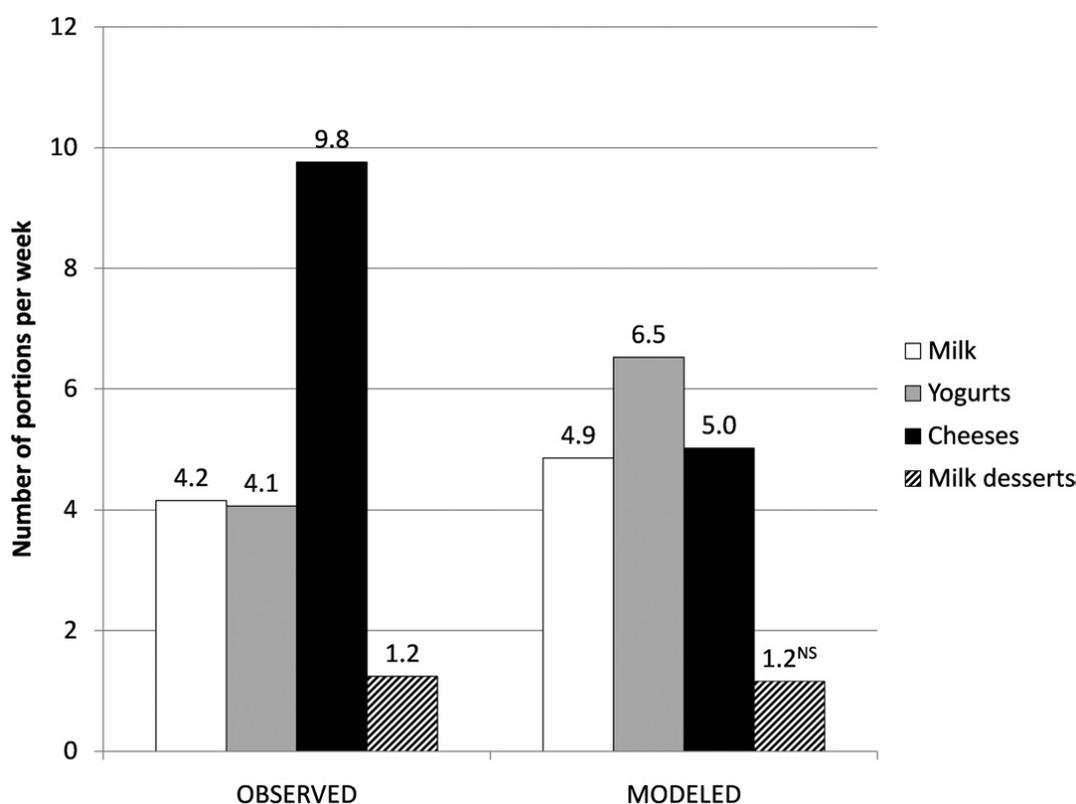
Figure. Number of portions[a] per week of milk-based food categories in observed (n=1,171) and modeled (n=1,171) diets of French adults. [a]The number of portions was computed using the following portion sizes: milk: 200 g, yogurts: 125 g, cheeses: 30 g, milk desserts: 100 g. NS=not significantly different from observed (P<0.05).

RESULTS

Presence, Weights, and Energy Contribution of Food Groups and Food Categories in Observed and Modeled Diets

Most diets contained foods from the seven food groups, but some differences were noticed between observed and modeled diets (Table 1). Interestingly, the groups of fruit and vegetables and of dairy products were added in all the diets where they were not initially present. Consequently, all the modeled diets (n=1,171) included foods from at least five of the seven food groups, namely fruit and vegetables; starches and grains; meat, fish, poultry, and eggs; added fats; and dairy products. Only mixed dishes and snacks, and sweets and savory products were absent from some of the modeled diets. Regarding the milk-based food categories, cheeses and milk desserts were removed from 62 and 23 diets, respectively, whereas yogurts and milk were added to 21 and 90 diets, respectively.

The optimization process significantly increased the weights of three food groups out of seven (Table 2), namely fruit and vegetables (+62%), starches and grains (+37%), and dairy products (+19%). In contrast, the weights of all the other food groups were reduced, namely mixed dishes and snacks (−58%); meat, fish, poultry, and eggs (−12%); added fats (−31%); and sweets and savory products (−15%). This is in line with the French[19] and other European[22] FBDG, where the top three messages relate to the three groups increased by the diet modeling process.

For all the food groups, with the exception of dairy products, an increase in weight was associated with an increase in energy and a decrease in weight was associated with a decrease

in energy. For the dairy products group, its energy contribution decreased (−225.7 kcal/week), despite its increase in weight (+306.9 g/week). This was explained by an increase of the dairy food categories with low energy density. Indeed, within the dairy products food group, the weights of milk and yogurts categories increased by 17% and 60%, respectively, whereas the weight of the cheeses category; that is, the most energy-dense category of the group, decreased by 48%. The energy and weight contributions of the milk desserts category did not change significantly, despite an overall decrease of the food group they belong to; that is, the sweets and savory products group.

Balance between the Four Milk-Based Food Categories in Observed and Modeled Diets

The optimization induced important changes in the balance between the four milk-based categories (Figure). In observed diets, cheeses represented one out of two consumed portions of foods from the milk-based categories when milk and yogurts each represented a fifth of the portions. In the modeled diets, each of those three categories represented about one portion per day. The number of portions of milk desserts remained constant before and after optimization, at approximately one portion per week. This stability shows the ability of the milk desserts category to fit into balanced diets at observed consumption levels, which is in accordance with the guideline that all foods can fit, with moderation.[23] Results from our modeling exercise are in line with the current French FBDG because they advise three dairy products per day while favoring "natural products and those richest in calcium, as well as products that are low in fat

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Table 3. Variation in nutrient content between modeled (n=1,171) and observed (n=1,171) French adult diets: total, by food group, and by food category

Food group	Protein (g/wk)	Lipids (g/wk)	Saturated fatty acids (g/wk)	Carbohydrates (g/wk)	Total sugars (g/wk)	Free sugars (g/wk)	Calcium (mg/wk)	Sodium (mg/wk)
Fruit and vegetables	27.9*	43.2*	4.5*	182.6*	161.6*	−0.4a	470.2*	233.1
Starches and grains	32.6*	16.3*	4.0*	195.1*	7.4*	2.0*	169.5*	1,048.7
Mixed dishes and snacks	−32.6*	−44.1*	−19.9*	−70.2*	−10.4*	−0.5*	−278.8*	−2,938.3
Meat, fish, poultry, and eggs	−24.1*	−54.5*	−21.4*	−0.9*	−1.0*	−0.1*	−2.3a	−1,888.6
Added fats	−0.8*	−51.5*	−45.0*	−0.5*	−0.6*	0.0a	−15.2*	33.4
Dairy products	−11.1*	−31.4*	−19.9*	25.4*	23.9*	2.9*	100.9*	−941.0
Milk	4.5*	1.9*	1.2*	6.5*	6.5a	0.0a	160.5a	64.9
Yogurts	13.6*	3.1*	2.0*	17.5*	17.5*	2.9*	511.8*	172.6
Cheeses	−29.2*	−36.5*	−23.1a	1.4*	−0.2a	0.0a	−571.4*	−1,178.5
Sweets and savory products	−1.8*	−4.1*	−10.2*	−38.3*	−37.0*	−37.1*	−29.5*	−215.6
Milk desserts	−0.6*	−1.2*	−0.6*	0.2*	−1.4a	−1.0a	−11.8a	−7.2
Biscuits	0.1*	−1.9*	−1.0*	2.2*	−1.1*	−1.2a	1.0a	26.0
Soft drinks	0.1*	0.0a	0.0a	−10.0*	−10.0*	−10.0*	−4.6*	−8.2
Desserts	1.5a	6.5a	−2.8*	−7.6*	−9.5a	−6.2a	−1.3a	−63.7
Sweets	0.1*	−0.2*	−0.2*	−13.3*	−13.3*	−17.5*	2.4*	3.5
Pastries	−2.9a	−7.2a	−5.3*	−9.8*	−1.6a	−1.1a	−9.5a	−104.9
Savory products	−0.2a	−0.2a	−0.3a	0.0	0.0*	−0.1a	−5.7a	−61.1
Total	−9.9*	−126.1*	−107.9*	293.2*	143.9*	−33.3*	414.8*	−4,668.3

aNot significantly different.
*Significantly different from 0 at $P<0.05$.

and salt: milk, yogurt, cottage cheese, etc."[19] However, they suggest that more precise recommendations on the balance between milk-based food categories could be provided to ease the fulfillment of nutrient needs.

Variation in Nutrient Content between Observed and Modeled Diets

Differences in nutrient contents between observed and modeled diets are shown in Table 3. The variations of nutrients provided by each food group generally followed the food group's change in weight. For instance, the large increase in the fruit and vegetables food group (including unsalted nuts) was associated with an increase in calcium but also with an increase in lipids, saturated fat, and sodium. In contrast, for the dairy products food group, the overall weight increase was associated with both an increase in calcium, and a decrease in lipids, saturated fat, and sodium. The contribution of the dairy products food group to the total decrease in saturated fatty acids and sodium was entirely due to a decrease in cheeses. The dairy products food group did not contribute to the total decrease in free sugars; the latter was mainly driven by the soft drinks and sweets decrease from the sweets and savory products group. The significant increase in calcium supplied by the dairy products food group was due to a large increase in calcium supplied by milk and yogurts, despite a concurrent decrease in the calcium supplied by cheeses.

The preference given by the model to milk and yogurts, rather than to cheeses for providing calcium in the diet highlights the nutritional value of these categories. Indeed, previous studies have shown that fresh dairy products have not only a lower energy density than cheeses but also a better overall nutrient profile, namely a higher nutrient density, and a lower content of nutrients to be limited.[18,24]

Our study presents several limitations. The INCA 1 study was not the latest one. However, differences in food consumption with the second, more recent 2007 INCA study (INCA 2) were shown to be modest.[25] The classification of foods sometimes needed the use of interpretation, but it was done in accordance to the already existing INCA classification, to the French FBDG, and to French eating habits. Another limitation is that the variation in the bioavailability of nutrients coming from different food sources was not taken into account in the model. In particular, introducing in the model the fact that calcium provided by most vegetables is less well absorbed than calcium from dairy products[26] may have increased the ratio of dairy products relative to vegetables in modeled diets. Finally, some changes in the

food selection made by the optimization process may be unrealistic. For instance, milk was added to 90 diets not initially containing it, but further investigations would be needed to assess the acceptability of such changes, notably regarding the possibility of lactose mal-absorption/intolerance in adults not consuming milk (given that lactose-free milk is an uncommon and expensive alternative in France). Our results are directly dependent on population-specific dietary patterns. For instance, the larger increase of yogurt compared with milk may be due, at least in part, to the higher number of consumers and to the wider variety of yogurts consumed compared with milk among INCA participants. Thus, repetition of the study using populations with different dietary patterns would lead to different modeled diets but they will still fulfill all nutrient constraints.

CONCLUSIONS

Individual diet modeling allowed us to quantify precisely the food changes needed to reach nutrient adequacy while departing the least from usual dietary patterns in the French adult population. These results confirm that a large increase of plant-based products is needed. They show that rebalancing the intake of milk-based products; that is, an increase in milk and yogurts and a decrease in cheeses consumption, will help individuals in this population reach nutritional adequacy. This new distribution between milk-based food categories is consistent with the emphasis put on the reduction of energy density to improve diet quality.[27] These conclusions also agree with recent studies showing a beneficial effect of yogurt consumption on health, in particular prevention of long-term weight gain,[28] and the reduction of metabolic disturbances such as the metabolic syndrome and type 2 diabetes.[29,30] We therefore suggest that the balance between different categories of dairy products should be explicitly highlighted by dietary guidelines.

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AUTHOR INFORMATION

E. Clerfeuille is a nutrition consultant, Conut.eu, Bures sur Yvette, France. M. Maillot is a postdoctoral fellow and N. Darmon is a research director, Nutrition, Obesity, and Risk of Thrombosis, INSERM, Marseille, France, INRA, Marseille, France, and Faculté de Médecine, Aix-Marseille University, Marseille, France. E. O. Verger is a PhD student, Nutrition Physiology and Ingestive Behavior, AgroParisTech, Paris, France, Nutrition, Physiology, and Ingestive Behavior, INRA, Paris, France, and Danone Research-Centre Daniel Carasso, Palaiseau, France. A. Lluch is a senior nutrition scientist and N. Rolf-Pedersen is a scientific affairs manager, Danone Research-Centre Daniel Carasso, Palaiseau, France.

Address correspondence to: Nathalie Rolf-Pedersen, PhD, Dairy Health Governance & Transformation, Danone Research, RD 128, 91767 Palaiseau, France. E-mail: nathalie.rolf-pedersen@danone.com