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Substituting meat or dairy products with plant-based substitutes has small and heterogeneous effects on diet quality and nutrient security – A simulation study in French adults (INCA3).

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Running title: Plant-based substitutes and diet quality

Abbreviations used: ALA, alpha-linolenic acid; ANSES, French Agency for Food, Environmental and Occupational Health and Safety; AS, Adequacy Subscore; CIQUAL, French Information Centre on Food Quality; DSCF, Dwass-Steel-Critchlow-Fligner test; INCA3, Third Individual and National Study on Food Consumption Survey; LA, linoleic acid; MS, Moderation Subscore; PANDiet, Probability of Adequate Nutrient Intake; SFA; saturated fatty acids; UPF, ultra-processed foods.

Abstract

Background: Plant-based substitutes are designed to have the same use as animal-based foods in the diet and could therefore assist the transition towards more plant-based diets. However, their nutritional impact has not been characterized.

Objective: We assessed and compared the effects of plant-based substitutes on the nutritional quality of the diet.

Methods: We simulated separately the substitution of meat, milk and dairy desserts with 96 plant-based substitutes in the diets of 2121 adults (18-79y) from the cross-sectional French national survey INCA3 (2014-2015). The quality of initial individual diets and the 203,616 substituted diets was evaluated using the PANDiet scoring system which assesses the probability of adequate (sufficient and not excessive) nutrient intake, and the nutrient security was evaluated using the SecDiet scoring system that assesses the risk of overt deficiency.

Results: Impacts on PANDiet depended on both the food substituted and the types of substitutes. Soy-based substitutes provided a slight improvement in diet quality (0.8% increase of the PANDiet score when substituting meat), whereas cereal-based substitutes resulted in a 1.1% decrease. Globally, substitutions led to better adequacies for fiber, linoleic acid, alpha-linolenic acid, vitamin E, folate and saturated fatty acids, but lower adequacies regarding vitamin B-12 and riboflavin, as well as bioavailable zinc and iron when substituting meat, and calcium and iodine when substituting milk/dairy desserts. When they substituted dairy products, calcium-fortified substitutes allowed to maintain calcium adequacy but there was a higher risk of iodine deficiency when substituting dairy which may warrant iodine fortification. Substitutions modified the energy share of ultra-processed foods from 29% to 27-40%, depending on the food substituted and the substitute employed.

Conclusion: Plant-based substitutes had little effect on overall diet quality but heterogeneous impacts on nutrient adequacy and security. Plant-based substitutes that include legumes appear more nutritionally adequate to substitute animal products than other substitutes.

Key words: Plant-based substitutes, Diet quality, Nutrient adequacy, Animal product substitution, Modelled diet.

Introduction

Reducing the consumption of animal foods is a key element in achieving healthy and sustainable diets (1–3). Increasing numbers of consumers are now willing to reduce or stop the consumption of animal products for environmental, health or ethical reasons (4,5). As for dairy products, along with environmental or ethical issues consumers may avoid milk consumption because of milk allergy or lactose intolerance, which has led to growing demand for alternatives (6,7).

Plant-based substitutes have been developed in this context and constitute a continuously expanding market (8,9). These products aim to mimic the sensory attributes and practical use of animal products (10,11). Dairy substitutes are made by extracting plant materials with water and can be further fermented to produce plant-based yogurt-like products (12). Plant-based meat substitutes, also called meat analogues or imitation meat, are generally made using soy, wheat or other plant proteins (9,10).

The advantage of these products is that they can easily substitute meat without modifying meal patterns and food habits (13), unlike pulses that require more knowledge of how to cook and consume them (14). Indeed, animal products, and especially meat, play an important role in structuring meals (13,15) and plant-based substitutes that have the same use could offer an efficient lever for their replacement and the adoption of more sustainable diets (11). These products also have less environmental impact than meat or milk and other meat substitutes (e.g. lab-grown meat, insect-based substitutes, etc.) (12,16,17).

However, little is known about the nutritional quality of these products. Indeed, many of those available are made using different ingredients and processing technologies (9,18). Since these products are designed to be used as a substitution of animal products, and animal and plant products do not bring the same nutrients (19,20), their true nutritional substitutability needs to be investigated. Furthermore, even if plant-based diets are generally associated with beneficial health

effects such as a lower risk of cardiovascular diseases (21,22), this is dependent on the types of plant-based foods being consumed (23,24). Plant-based substitutes are often ultra-processed (9,18) and the excessive consumption of ultra-processed foods has been associated with several adverse health effects (25–27).

Several studies have investigated the nutrient content of meat or milk substitutes (7,8,28) or the potential impacts of using meat substitutes when modelling healthy eating patterns (29). However, no study has assessed the expected nutritional impact of using plant substitutes, or analyzed the degree to which this may vary depending on the types of substitutes. The objective of this study was therefore to simulate, in a French adult population, the substitutions of meat, milk or dairy desserts separately with different types of plant-based substitutes in order to analyze the potential impacts of these substitutions on diet quality and nutrient security.

Subjects and methods

Population data

The data used in this study came from the third French Individual and National Study on Food Consumption Survey 3 (INCA3), which is a nationwide and representative cross-sectional survey. This study was performed in mainland France in 2014-2015 and its methods, design and participant characteristics have been fully described elsewhere (30,31). Participants over 18y were included in the study and the sample contained 2121 adults (887 men and 1234 women, aged 18-79y, median age 51y).

Dietary data

The foods and beverages consumed by individuals were obtained through three non-consecutive 24h-dietary recalls consisting of two weekdays and one weekend day spread over three weeks. Dietary data were collected by a telephone interview assisted by dietary software. The participants were not aware of the days of recall so they could not change their diet in anticipation of the call. Validated photographs were used to estimate portion sizes (30). The nutrient contents of different foods and beverages were extracted from the 2016 food composition database from the French Information Centre on Food Quality (CIQUAL) (32).

Food items were broken down into their ingredients in order to identify the origin (animal or plant) of each ingredient and determine the amounts of plant protein in each food item and then in the diet of each participant. The NOVA classification (33,34) was applied to all food items consumed in the INCA3 survey (Supplemental Method 1). This classification comprises four groups: “unprocessed/minimally processed foods”, “processed culinary ingredients”, “processed foods” and “ultra-processed foods” (UPF). When the food was home-made, eaten in a restaurant or made by an artisan, the NOVA classification was applied to the ingredients constituting the food item. In other cases, the NOVA classification was directly applied to the food items. Only UPF were

considered in our study, and the proportion (%) of total energy intake from UPF was calculated for each participant.

Database on plant-based substitutes

The nutritional compositions of plant-based substitutes were gathered from three databases: CIQUAL food composition databases version 2016 (32) and version 2020 (35) and the food composition database from the NutriNet-Santé study (36). Three types of substitutes were used for this study: meat substitutes, milk substitutes and dairy dessert substitutes. Pulses were also included in the study as a benchmark for meat substitution. The final database contained 56 meat substitutes, 16 milk substitutes and 24 dairy dessert substitutes (Supplemental Table 1). The substitutes were classified in two different ways: according to the category (e.g. a plant-based burger, or a plain plant-based milk) and according to the main protein ingredient in the substitute (e.g. soy-based or cereal-based) (**Table 1**). Milk and dairy dessert substitutes were categorized as “sweet” if they contained at least 5g of sugars and as “calcium-fortified” if they contained at least 80mg calcium, or if the name explicitly specified “fortified with calcium”. This classification was inspired from the classification of dairy product proposed by the French Agency for Food, Environmental, and Occupational Health and Safety (ANSES) for the construction of food consumption guidelines for the French population (37). In the same way as for the INCA3 survey, plant-based substitutes were broken down into ingredients to determine the percentage of plant protein (because some of them may contain cheese or egg). The NOVA classification was also applied to plant-based substitutes.

Simulations of substitutions of meat or dairy with plant-based substitutes

Identification of substitutable food items

First, we identified all animal-based food items consumed by the INCA3 population that could be replaced by plant-based substitutes on the basis that food items and substitutes are generally

consumed in the same way during a meal. In the case of meat, all pieces of meat usually consumed in a main dish were considered to be substitutable. Meat food items were divided into three categories (Beef/lamb/game, Poultry/rabbit and Pork/sausage). With respect to milk, all milk food items, except milk powder or condensed milk, were considered to be substitutable. For dairy desserts, all prepacked yogurts, custard desserts and other dairy desserts (e.g. rice pudding) were considered to be substitutable. Prepacked mousses were also included in dairy desserts. Animal-based ingredients in composite dishes (e.g. pizza, lasagna) were not considered to be substitutable.

Method of substitution

For each individual, we simulated the substitution of substitutable animal-based food items, as defined above, with the same quantity, in grams, of a plant-based substitute, under the rationale that the portion sizes of animal foods and their plant-based substitutes are generally the same (e.g. a glass of milk or of milk substitute will have the same portion size). Then, at the individual level, the difference in energy value between the animal-based food items and the plant-based substitute was reported equally on all other food items consumed (excluding beverages) in order to maintain the same total energy intake without alcohol.

We used three separate substitution models (Supplemental Figure 1). The first was the “Meat substitution model” where all meat food items were substituted. This model was further broken down into three sub-models: “Beef substitution model” where all beef, veal, lamb, horse and game meats were substituted; “Pork substitution model” where all pork meats and sausages were substituted and the “Poultry substitution model” where all poultry and rabbit meats were substituted. The second model was the “Milk substitution model” where all milk items were substituted. The third model was the “Dairy dessert substitution model” where all prepacked dairy dessert (including yogurts) items were substituted. For all models, animal-based food items other

than those concerned were not replaced (e.g. in the case of the “Meat substitution model”, milk or dairy desserts were not replaced).

For every model, all substitutable food items were replaced by the same plant-based substitute and we implemented as many substitutions as we had plant-based substitutes available. For example, in the “Meat substitution model”, the first substitution involved all meat items being replaced by the “Falafel” substitute, while under the second substitution they were replaced by the “Plant-based sausage with wheat or seitan” substitute, until all substitutes had been tested. Fifty-six substitutes were available for the “Meat substitution model”, so we implemented 56 different replacements. In the same way, 16 replacements were made under the “Milk substitution model” and 24 under the “Dairy dessert substitution model”. All individual diets were then evaluated for their nutritional quality. The simulation yielded a total of 2121x96=203,616 simulated diets.

Evaluation of the nutritional quality of the diet

Diet quality was evaluated using an updated version of the Probability of Adequate Nutrient Intake (PANDiet) scoring system (38) that took account of the most recent dietary reference intakes released by ANSES (39) (Supplemental Table 2). The PANDiet was preferred over other assessments of adequacy of nutrients intakes since it enables to use an overall index for the population that could better capture the evolution of diet quality between initial and substituted diets. In brief, the PANDiet score measures the probability of having an adequate overall nutrient intake at an individual level. It is the mean of two sub-scores: The Adequacy Sub-score (AS) and the Moderation Sub-score (MS). The AS measures the probabilities of adequacy of intake for 27 nutrients whose intake needs to be above the nutrient reference value, and is the mean of all probabilities of adequacy multiplied by 100. The MS measures the probabilities of adequacy of not having an excessive intake for 6 nutrients whose intake should be below an upper bound reference value, and is the mean of all probabilities of adequacy multiplied by 100. For each nutrient, the probability of adequacy is calculated using the mean intake, the intra-individual

variability of intake, the variability of the requirement and the nutrient reference value. AS, MS and PANDiet values range from 0 to 100 and higher scores indicate better nutrient adequacy, better moderation of the diet and better nutritional quality of the diet, respectively.

Evaluation of the nutrient security of the diet

Nutrient security of the diet was estimated using the SecDiet score which measures the risk of having an overt nutrient deficiency (40). It is calculated as the mean of the squares of the probabilities for 12 nutrients of having a sufficient intake to avoid nutrient deficiency. The nutrients included in the SecDiet are vitamin A, thiamin, riboflavin, niacin, folate, vitamin B-12, vitamin C, iodine, selenium, iron, zinc and calcium. A deficiency threshold has been defined for each nutrient as the minimal intake below which clinical signs of deficiency may appear (Supplemental Table 3). These thresholds are generally much lower than classical dietary reference intakes, since dietary reference intakes generally go beyond the mere prevention of overt deficiency. Therefore, the SecDiet does not measure classical adequacy of nutrient intakes but the risk of deficiency that could arise if nutrient intakes are below deficiency thresholds. In the same way as for the PANDiet, the probability of having a sufficient intake for each nutrient is calculated from the mean intake, intra-individual variability of intake, variability of the requirement and the nutrient reference value (here defined using the threshold value). SecDiet values range from 0 to 1 and a higher score reflects a lower risk of nutrient deficiency.

Statistical analysis

For the initial diet and each substitution in each model, the PANDiet and SecDiet scores and associated probabilities, and the proportions of plant protein intake and total energy intake from UPF were calculated. The three substitution models were analyzed separately. For each model, only participants who had consumed at least one substitutable food item were included in the analyses (n=1949 for the “Meat substitution model”, n=837 for the “Milk substitution model” and

n=1666 for the “Dairy dessert substitution model”). Mean substitutions were calculated by averaging for each individual the results of replacements using substitutes from the same substitute category or from the same main constituting ingredient. Differences between the initial diet and mean substitutions diet were then assessed using ANOVA. Post-hoc tests were performed using a Bonferroni correction for multiple comparisons. For the SecDiet score and associated probabilities, because of their particular skewed distributions, Kruskal-Wallis non-parametric and post-hoc Dwass-Steel-Critchlow-Fligner (DSCF) tests were run. Means are presented as means ± SD and differences between means are presented with a 95% CI.

All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA.). Significance was set at $P<0.05$.

Results

Substitution of meat food items with plant-based meat substitutes ("Meat substitution model")

When replacing meat food items with plant-based meat substitutes (n=1949 consumers), the mean PANDiet score ranged from 67.1 to 70.4 (vs 68.3 for the initial diet) across the different substitution diets (i.e. across the different plant-based substitutes used). In particular, the AS ranged from 59.6 to 66.0 (vs 63.7) and the MS from 72.0 to 76.9 (vs 73.0). The SecDiet score ranged from 0.89 to 0.94 (vs 0.92). On average over all the substitutes used, diet quality and nutrient security were therefore only marginally affected by the substitution. By contrast, the percentage of plant protein increased (ranging from 45.2% to 61.5% vs 31.7% in the initial diet), as did the percentage of energy intake from UPF (except with cooked pulses, tofu and tempeh) which ranged from 27.2% to 39.5% (vs 28.6% in the initial diet) (**Table 2**).

More specifically regarding the substitutes used, the PANDiet score was increased after substitutions using "Tofu, tempeh or soy protein" (+1.58 points) or "Soy-based" (+0.57 points) substitutes and decreased with "Plant-based sausage" (-0.60 points) or "Cereal-based" (-0.72 points) substitutes (all *P*s<0.0001). In particular, the AS score remained stable or decreased (the most important decrease concerning substitution with "Cereal-based" substitutes (-3.08 points, *P*<0.0001)) while the MS remained stable or increased (the greatest increase concerning "Plant-based beaded food" substitutes (+2.51 points, *P*<0.0001)) (**Figure 1**, Supplemental Tables 4 and 5).

At a more detailed level, the probabilities of adequacy of the AS score (i) increased (i.e. better nutrient adequacy) in most mean substitution diets for fiber, linoleic acid (LA), α-linolenic acid (ALA), folate, calcium, and vitamin E and to a lesser extent for manganese, magnesium and copper, and (ii) decreased (i.e. less nutrient adequacy) for vitamin B-12, bioavailable zinc, vitamin B-6, bioavailable iron, riboflavin and protein and to a lesser extent for pantothenic acid. The

probabilities of adequacy of the MS score (i) increased (i.e. less excessive intake) for saturated fatty acids (SFA) and to a lesser extent for total fat and protein, and (ii) decreased (i.e. more excessive intake) for sodium and to a lesser extent for carbohydrates (Supplemental Tables 4 and 5).

The SecDiet score decreased after substitution with “Plant-based breaded food” (-0.01 points, *P*=0.0011) and “Cereal-based” (-0.02 points, *P*<0.0001) substitutes **(Figure 2)**. Probabilities decreases (i.e. an elevated risk of deficiency) were the most important for riboflavin (max. -0.05 points, *P*<0.0001), vitamin B-12 (max. -0.05 points, *P*<0.0001) and bioavailable iron (max. -0.03 points, *P*<0.0001), whereas probabilities increased (i.e. less risk of deficiency) for folate (max. +0.04 points, *P*<0.0001) and calcium (max. +0.03 points, *P*<0.0001).

In sub-models of substitution, beef/lamb/game, poultry/rabbit and pork/sausage were separately substituted (Supplemental Figure 2). The variations observed in PANDiet, AS and MS scores regarding the substitutions of beef/lamb/game were comparable to those of all meat food items. For the substitution of pork/sausage, the PANDiet and MS scores of substitution diets mainly increased when compared to the initial diet. Regarding the substitution of poultry/rabbit, the variations were not significant, except in the case of substitution with “Tofu, tempeh or soy protein” substitutes that increased the PANDiet score.

Substitution of milk items with plant-based milk substitutes (“Milk substitution model”)

When replacing milk items with plant-based milk substitutes (n=837 consumers), the PANDiet score across the different substitution diets ranged from 66.7 to 70.0 (vs 69.0 for the initial diet). The AS ranged from 62.2 to 67.4 (vs 64.8) and the MS from 71.1 to 73.4 (vs 73.3). The SecDiet score mainly decreased (0.91-0.93 vs 0.93 for the initial diet). The percentage of plant protein in the diet increased systematically (34.1% - 38.9% vs 31.4% in the initial diet) as the percentage of energy intake from UPF (31.6% - 34.8% vs 29.6%) (Table 2).

More specifically, after substitution, the PANDiet and AS scores mostly decreased with “Sweet plant-based milk” (–1.19 points for PANDiet, *P*=0.0005, and -1.89 points for AS, *P*=0.0133) and “Nut-based” (-1.19 points for PANDiet, *P*<0.0001, and -1.81 for AS, *P*=0.0001) substitutes, while the MS did not significantly vary (Figure 1). In more detail, for most mean substitution diets, the probabilities of adequacy of the AS score increased for LA, ALA, fiber, bioavailable iron, and slightly for manganese, vitamin E and copper, whereas probabilities decreased for calcium, vitamin B-12, riboflavin, iodine, potassium, and slightly for pantothenic acid and protein. For calcium, the decrease was only significant with unfortified plant-based milk substitutes. The probabilities of adequacy of the MS score increased for SFA but decreased for sugars without lactose (Supplemental Tables 6 and 7).

The SecDiet score systematically decreased after substitution, and the most marked decreases were obtained with “Nut-based” and “Sweet plant-based milk” substitutes (both -0.02 points, *Ps*<0.0001) **(Figure 3)**. The decreases in probabilities were the most marked for iodine (max. -0.06 points, *P*<0.0001), riboflavin (max. -0.05 points, *P*<0.0001), calcium (max. -0.04 points, *P*<0.0001) and vitamin A (max. -0.03 points, *P*<0.0001). The calcium probability did not decrease with “Plain plant-based milk, calcium-fortified” and “Sweet plant-based milk, calcium-fortified” substitutes.

Substitution of dairy dessert items with plant-based dairy dessert substitutes (“Dairy dessert substitution model”)

When replacing dairy dessert items with plant-based dairy dessert substitutes (n=1666 consumers), the PANDiet scores across the different substitution diets ranged from 65.2 to 70.0 (vs 68.5 for the initial diet). The AS ranged from 61.3 to 66.4 (vs 64.3 for the initial diet) and the MS from 69.2 to 74.3 (vs 72.7). The SecDiet ranged from 0.89 to 0.93 (vs 0.93 for the initial diet). The percentage of plant protein in the diet (initially 32.1%) increased between 34.5% and 42.3%.

The percentage of energy intake from UPF (initially 29.3%) generally increased, to reach between 28.9% and 40.5% (Table 2).

More specifically, the PANDiet score increased with “Plain plant-based dessert, calcium-fortified” (+1.35 points), “Plain plant-based dessert” (+0.93 points) and “Soy-based” (+0.60 points) substitutes and decreased with “Plant-based mousse” (-2.85 points) and “Non-soy based” (-1.31 points) substitutes (all *P*s<0.0001). The AS increased with “Plain plant-based dessert, calcium-fortified” substitutes (+1.77 points, *P*<0.0001) and both the AS and the MS decreased with “Plant-based mousse” (-2.46 points for AS, *P*<0.0001, -3.24 points for MS, *P*<0.0001) and “Non soy-based” (-1.25 points for AS, *P*=0.0008, -1.36 points for MS, *P*<0.0001) substitutes (Figure 1).

In more detail, the probabilities of adequacy of the AS score increased for LA, fiber, ALA and bioavailable iron, and to a lesser extent for vitamin E, copper, manganese and magnesium, while they decreased for calcium, riboflavin and iodine and to a lesser extent for pantothenic acid. The probability of calcium adequacy did not decrease with calcium-fortified substitutes. The probabilities of adequacy of the MS score increased for SFA, except for “Plant-based mousse” where it decreased (Supplemental Tables 8 and 9).

The SecDiet score significantly decreased after all substitutions, except with calcium-fortified plain plant-based desserts. The lowest scores were obtained for “Plant-based mousse” (-0.03 points, *P*<0.0001) and “Non soy-based” (-0.02 points, *P*<0.0001) substitutes **(Figure 4)**. The most important reductions in probabilities were observed for iodine (max. -0.09 points, *P*<0.0001), calcium (max. -0.08 points, *P*<0.0001) and riboflavin (max. -0.07 points, *P*<0.0001).

Discussion

In this study, we modeled the substitution of animal foods with plant-based substitutes and evaluated its effects on diet quality and the risk of deficiency, using in depth assessments based on nutrient intakes. The issue of the nutritional quality of plant-based substitutes is usually addressed by comparing the nutrient contents of food products, often with information on a reduced set of nutrients and not taking account of the frequency and amounts consumed or the importance of nutrients to public health. By contrast, our study offers an integrated quantitative assessment of the true expected impact of such changes at the level of whole diets.

The main finding of our study was that the nutritional impact of substitution depended on both the food products replaced and the types of plant-based substitutes employed. Nonetheless, there were some common trends for certain nutrients across the different substitution models.

<u>Impacts of substitutions on nutrients that need to be limited</u>

First, we found that the substitution of animal products led to an increase in the probabilities of adequacies of the MS, meaning a less excessive intake of nutrients that should be consumed in limited amounts. The same effect was observed in a previous study where the favorable evolution of the MS was mostly ascribed to the reduction in the consumption of animal products rather than the increase in the consumption of plant-based products (41). This increase was mainly observed for SFA, and consequently for total fat, and was further illustrated by the substitution of different meat types, where the MS score increased when replacing pork/sausage and beef/lamb/game but not poultry/rabbit meat, which is mostly lean. However, the consumer samples were different, thus limiting the comparison between meat types.

By contrast, we found decreases in the probabilities of adequate sodium intake in the meat substitution model, except when substitutions were made using “Cooked pulses” or “Tofu, tempeh or soy protein”. Sodium intake was increased from initially 3200mg/day to 3400mg/day on

average. Sodium intake is already much exceeding recommendations and reduction of intake is advised to reduce the risk of chronic diseases (42). This increase could be explained by the fact that plant-based meat substitutes are often seasoned with salt in order to improve taste or preservation, as it is often the case for ultra-processed foods (18,33). In the case of dairy products, probability of adequate intake of sugars without lactose decreased for sweet substitutes. These results might be mitigated because these substitution scenarios did not take account of the fact that consumers might adjust the seasoning (i.e. salt or sauces for meat products and sugary products for dairy desserts) depending on the product they were consuming.

Impact of substitutions on nutrient adequacy and security

Another important finding of this study was that the modeled substitutions had a limited overall effect on nutrient adequacy, but the profile of nutrient adequacy was changed because animal-based and plant-based products do not make the same contribution to nutrient intakes (19,43). For all modelled substitutions (meat, milk or dairy desserts), probabilities of adequacy increased for fiber, LA, ALA, vitamin E (and folate for meat substitution) and, to a lesser extent, for copper, manganese and magnesium. Higher consumption of fiber, ALA and LA is expected to have important health benefits (44–46) and plant-based products could contribute to increase the low intakes currently observed in the population. At the same time, we found decreases in the probabilities of adequacy for riboflavin, pantothenic acid, vitamin B-12 and protein and a small increase in the risk of clinical deficiency for riboflavin and vitamin B-12. Indeed, all these nutrients are largely provided by meat and dairy products (19,20). After meat substitution, probabilities of adequacy decreased for bioavailable iron and zinc, whereas the probability of adequacy for bioavailable iron slightly increased with the substitution of dairy foods.

For the substitution of milk or dairy desserts, the probability of adequacy for calcium decreased, and the risk of deficiency increased when using non-calcium-fortified substitutes. Therefore, to maintain a similar calcium intake, fortifying substitutes with calcium would appear to be an

appropriate security measure. Dairy substitution also resulted in a reduction in probabilities (both adequacy and risk of deficiency) for iodine. Whereas dairy products are an important source of iodine in several countries because of dairy farming practices (47,48), the iodine content of plant-based milk alternatives is much lower than that of cow's milk (47,49). Current iodine status is suboptimal (50) and given the importance of iodine, especially in sub-populations such as pregnant women, fortifying plant-based dairy products with iodine could offer an interesting lever. Of course this question should be considered taking into account current public health strategies regarding iodine fortification (51).

Impact of substitutions depending on the type of substitutes

Finally, we could draw comparisons between different types of plant-based substitutes. For all modelled substitutions, it appeared that soy-based substitutes led to a slight improvement in diet quality. Soy is generally preferred for plant-based substitutes because of its textural properties and high protein content (9). Soy-based substitutes may also have a more favorable nutrient content, as reported in a US study according to which soy-based substitutes contained more fiber, omega-3-fatty acids, iron, zinc, thiamine, riboflavin, vitamin B6 and folates than other substitutes (28). In contrast, we found that cereal-based substitutes decreased nutrient adequacy and security. Since cereals are currently the main contributors of plan protein in western diets (52), diversifying plant-protein sources is indeed preferable for nutrient adequacy when replacing animal with plant protein (41).

As for milk substitutes, it has been shown that soy and almond milks have a better nutrient composition than coconut milk (which is rich in saturated fat) and rice milk (which is often high in sugars) (7). This would explain why we found that nutrient adequacy was globally maintained with soy-based substitutes and slightly decreased with cereal and nut-based substitutes. As already mentioned, we also found differences between plain vs. sweet and calcium-fortified vs. unfortified drinks. From our results, plain soy-based calcium-fortified substitutes appeared to be best

substitutes for milk, and the same conclusion can be drawn for plant-based desserts. The case of plant-based mousses was quite particular because they were rich in energy (269kcal/100g on average vs 86kcal/100g on average for other substitutes), and since the substitutions were isocaloric, this led to an important adjustment over the consumption of the rest of the diet which finally resulted in unbalancing the diets.

One final aspect that needs to be highlighted regarding plant-based substitutes, and in particular meat substitutes, is that they may contain many ingredients and be heavily processed to mimic meat as best as possible (9). We found that replacing meat with plant-based substitutes would increase the percentage of energy intake from UPF. Therefore, minimally-processed substitutes (such as tofu, tempeh or pulses) might be preferred to limit UPF consumption, all the more that they had similar, an even more beneficial, impacts on diet quality than ultra-processed substitutes. However, another study found that people following vegetarian diets consumed more UPF, partly due to the consumption of plant-based substitutes, and that an increased consumption of UPF was associated with the recent introduction of a vegetarian diet (53). Indeed, these products might be easier to consume when individuals start to reduce their meat consumption.

Limitations of the study

Although this study used quite a large set of 96 substitutes (including pulses) whose full and detailed nutrient composition was available, we may not have described exhaustively the plant-based substitutes market which is very recent and dynamic. Nevertheless, this sample was diversified and contained the principal types of substitutes. Consumer preferences and behavior were not taken into account in this study, and all the products within a category were replaced, regardless of the rest of the diet. We substituted all items from the same category with the same substitute without matching food items with the closest plant-based substitute in term of appearance, because this was needed to compare plant-based substitutes between them. The changes thus simulated could therefore be considered as not being entirely realistic, but we

believe that this was an effective method to study the nutritional quality of plant-based substitutes insofar as the nutritional quality of a food product is better evaluated by considering its impact when integrated in the whole diet. This also enabled us to highlight nutrients of concern with respect to the current consumption of a population. Lastly, by comparing each individual with themselves after simulated changes in the diet of individuals, modeling studies offer comparisons that are free of confounding factors such as the sociodemographic characteristics of individuals. It should be noted that this exploratory study ran many comparisons across variables and factors that could have much inflated type I error, but we limited this trend using Bonferroni corrections. Finally, since we wanted to analyze the variability of the impacts of substituting meat, milk or dairy desserts separately according to substitute, we did not estimate the impact of substituting these three categories at the same time.

Conclusion

In the present study, we analyzed the impacts on diet quality and nutrient security of substituting meat, milk and dairy desserts with corresponding plant-based substitutes in a French adult population. Substitutions improved the moderation score but had mixed effects on adequacy since the nutrient adequacy profile was modified. Impacts on nutrient security remained limited but attention should be given to certain nutrients, namely iodine and calcium when replacing milk and dairy desserts, and bioavailable iron and vitamin B-12 when replacing meat. Adjustments of the rest of the diet or improving the composition of substitutes could help solve these issues (29,54), and would requires further investigation.

Overall, the impact of plant-based substitutes on diet quality was small but varied: the nutritional impact of some substitutes proved to be positive, such as those that include legumes, but others proved to be negative, such as plant-based mousse as a replacement for dairy desserts. If seeking to limit the share of ultra-processed foods in the diet, pulses, tofu or tempeh offer a good alternative to other substitutes.

Acknowledgments and statement of authors' contributions to manuscript

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MS, FM and J-FH: designed the research; MS and CL: conducted the research and performed statistical analysis; MS and FM: analyzed the results; J-FH, EK-G and HF provided methodological support; MS and FM: wrote the manuscript; all authors provided critical comments on the manuscript; MS and FM: had primary responsibility for the final content and all authors read and approved the final manuscript.

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Table 1. Classification of meat, milk or dairy dessert substitutes according to the substitute category or the main constituting ingredient.

Type of substitute	Substitute category	Main constituting ingredient
Meat substitutes (n=56)	Cooked pulses (n=13) Tofu, tempeh or soy protein (n=3) Plant-based burgers (n=24) Plant-based sausages (n=5) Plant-based meat balls or slices (n=5) Plant-based breaded foods (n=6)	Pulse-based (n=18) Cereal-based (n=6) Soy & Wheat-based (n=11) Soy-based (n=21)
Milk substitutes (n=16)	Plain plant-based milks (n=7) Plain plant-based milks, calcium-fortified (n=3) Sweet plant-based milks (n=4) Sweet plant-based milks, calcium-fortified (n=2)	Soy-based (n=6) Cereal-based (n=3) Nut-based (n=7)
Dairy dessert substitutes (n=24)	Plain plant-based desserts (n=2) Plain plant-based desserts, calcium fortified (n=2) Sweet plant-based desserts (n=10) Sweet plant-based desserts, calcium fortified (n=8) Plant-based mousses (n=2)	Soy-based (n=19) Non soy-based (n=5)

Table 2. PANDiet, AS, MS and SecDiet scores, percentages of plant protein and total energy from UPF in the initial diet and substitution diets under the three substitution models (Meat, Milk and Dairy dessert) in the French adult population[1].

	PANDiet score	Adequacy Sub-score	Moderation Sub-score	SecDiet score	Plant protein (% of total protein)	UPF (% of total energy intake)
Meat substitution model (n=1949 consumers)						
Initial diet[2]	68.3 ± 6.2	63.7 ± 13.8	73.0 ± 11.9	0.92 ± 0.09	31.7 ± 9.2	28.6 ± 15.3
Substitution diets[3] (n=56 diets)	68.6 [67.1-70.4]	63.2 [59.6-66.0]	74.0 [72.0-76.9]	0.92 [0.89-0.94]	53.1 [45.2-61.5]	33.9 [27.2-39.5]
Milk substitution model (n=837 consumers)						
Initial diet	69.0 ± 6.1	64.8 ± 13.5	73.3 ± 11.8	0.93 ± 0.09	31.4 ± 9.1	29.6 ± 15.6
Substitution diets (n=16 diets)	68.4 [66.7-70.0]	64.0 [62.2-67.4]	72.8 [71.1-73.4]	0.92 [0.91-0.93]	36.2 [34.1-38.9]	33.2 [31.6-34.8]
Dairy dessert substitution model (n=1666 consumers)						
Initial diet	68.5 ± 6.1	64.3 ± 13.5	72.7 ± 11.8	0.93 ± 0.09	32.1 ± 9.4	29.3 ± 15.2
Substitution diets (n=24 diets)	68.6 [65.2-70.0]	64.3 [61.3-66.4]	72.9 [69.2-74.3]	0.92 [0.89-0.93]	37.7 [34.5-42.3]	31.8 [28.9-40.5]

[1]Data from Individual and National Study on Food Consumption Survey 3, n=2121. AS, Adequacy sub-score; MS, Moderation sub-score; PANDiet, Probability of Adequate Nutrient Intake; UPF, Ultra-processed foods.
[2] Values are mean ± SD.
[3] Values are mean [min, max]. Means are obtained by averaging the means of all the substitution diets of a substitution model (Meat, Milk or Dairy dessert). Min and max are respectively the lowest and the highest means between all the substitution diets of a substitution model.

Figure Legends

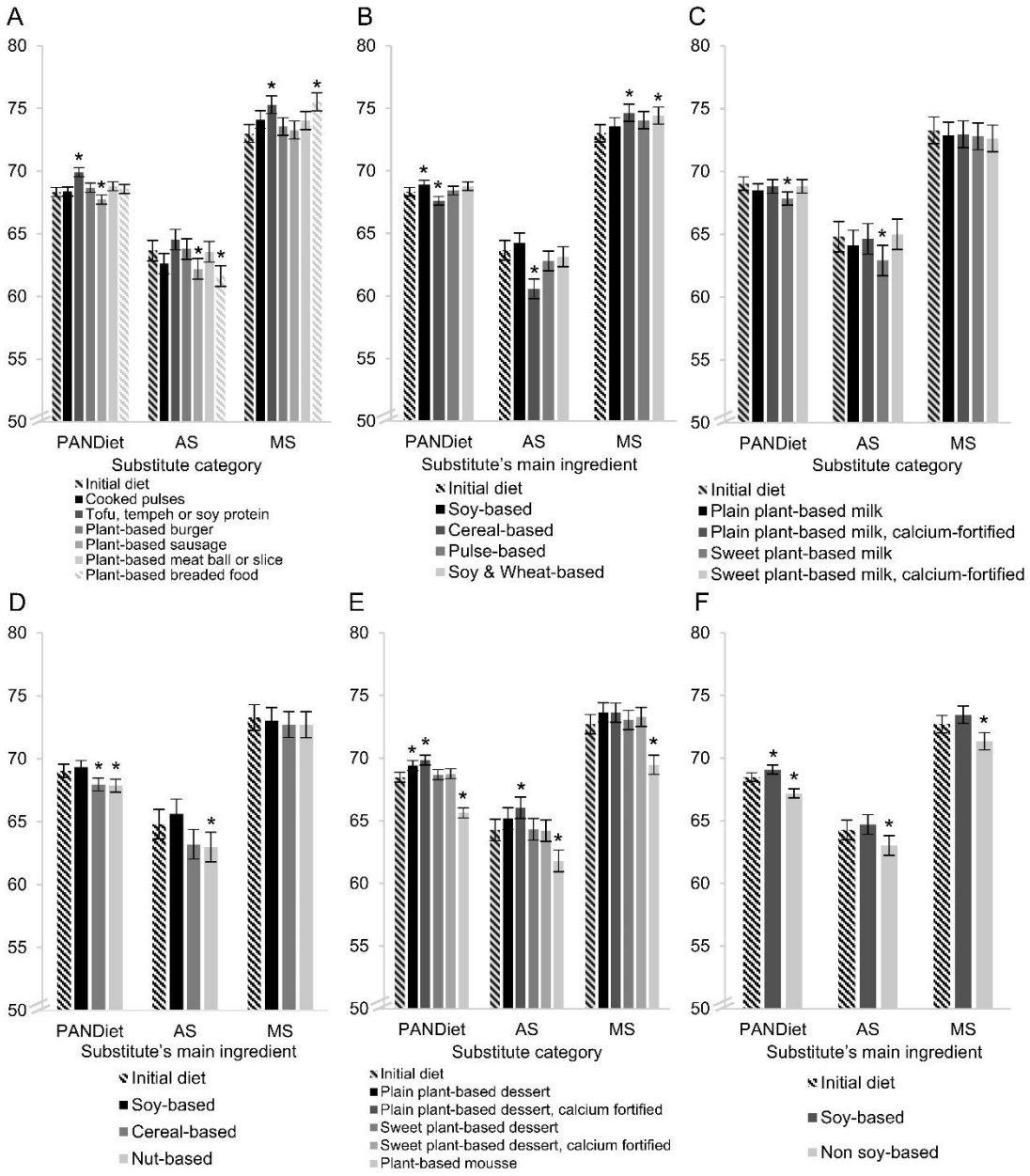


Figure 1. PANDiet score, Adequacy Sub-score (AS) and Moderation Sub-score (MS) for the initial diet and substitution diets according to the substitute category or to the main constituting ingredient of the substitute, for the three substitution models. (A, B) "Meat substitution model" (n=1949) simulated diets gathered by substitute categories (A) or by the main constituting ingredient of substitutes (B); (C, D) "Milk substitution model" (n=837) simulated diets gathered by

substitute categories (C) or by the main constituting ingredient of substitutes (D); (E, F) “Dairy dessert substitution model” (n=1666) simulated diets gathered by substitute categories (E) or the main constituting ingredient of substitutes (F). Values are means with 95% confidence intervals of the mean. * Significantly different from the initial diet, assessed using ANOVA and post-hoc tests with Bonferroni correction, at P<0.05. AS, Adequacy sub-score; MS, Moderation subscore; PANDiet, Probability of Adequate Nutrient Intake.

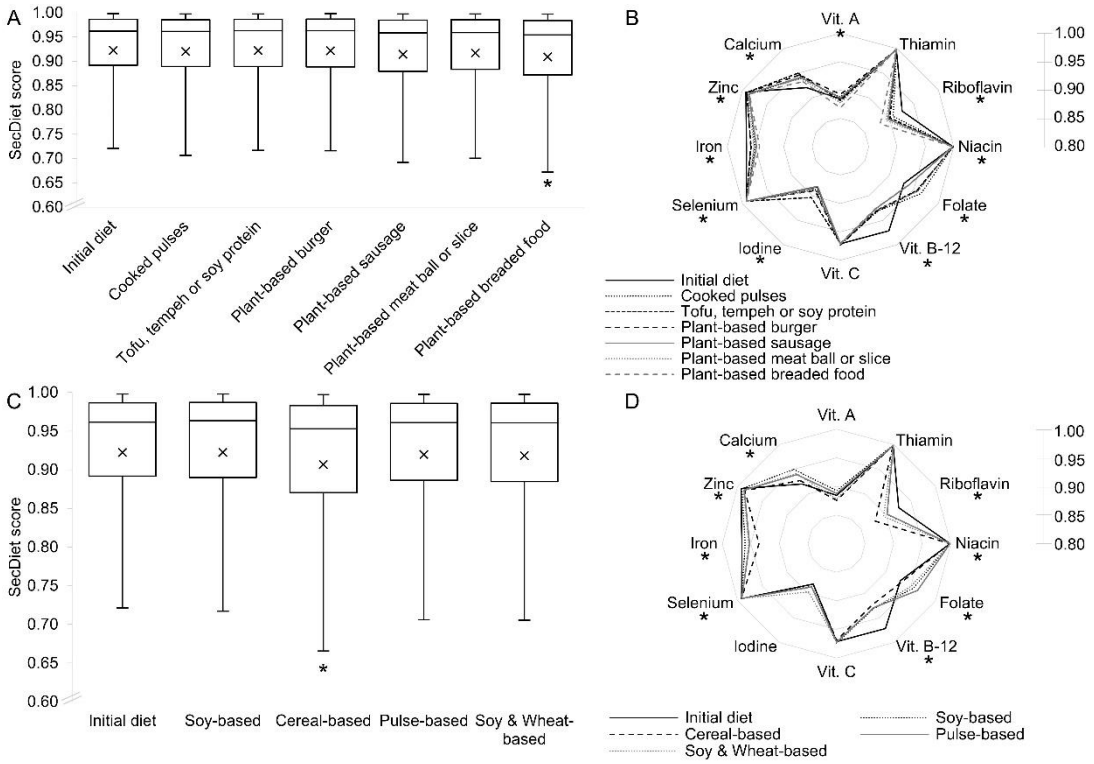


Figure 2. SecDiet score and probabilities for nutrients included in the SecDiet of avoiding overt nutrient deficiency in the initial diet and substitution diets of the “Meat substitution model” (n=1949). (A) SecDiet score and (B) its constituent probabilities in simulated diets gathered by substitute categories. (C) SecDiet score and (D) its constituent probabilities in simulated diets gathered by the main constituting ingredient of substitutes. (A, C) Lower and upper whiskers are respectively 5th and 95th percentiles; * Significantly different from the initial diet, assessed by

Kruskal-Wallis and DSCF tests. (B, D) Values are means, error bars are not presented for the sake of clarity; * *P*(model)<0.05 for the nutrient probability, assessed by Kruskal-Wallis tests.

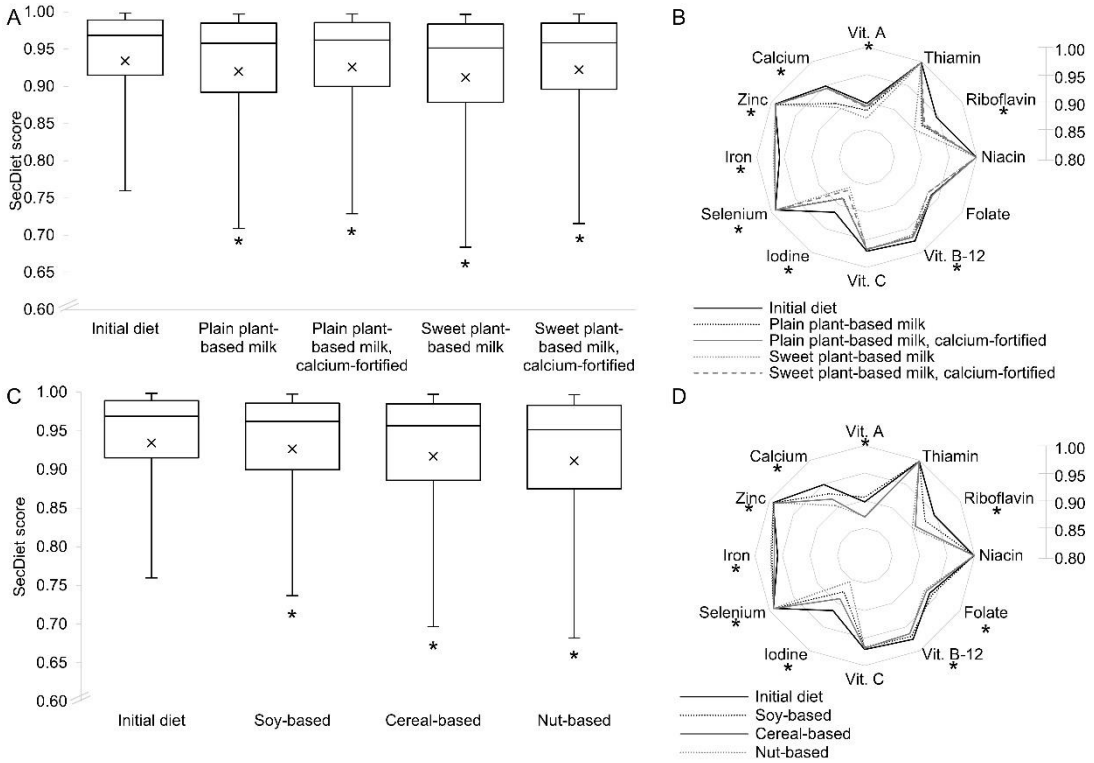


Figure 3. SecDiet score and probabilities for nutrients included in the SecDiet of avoiding overt nutrient deficiency in the initial diets and substitution diets of the “Milk substitution model” (n=837). (A) SecDiet score and (B) its constituent probabilities in simulated diets gathered by substitute categories. (C) SecDiet score and (D) its constituent probabilities in simulated diets gathered by the main constituting ingredient of substitutes. (A, C) Lower and upper whiskers are respectively 5th and 95th percentiles; * Significantly different from the initial diet, assessed by Kruskal-Wallis and DSCF tests. (B, D) Values are means, error bars are not presented for the sake of clarity; * *P*(model)<0.05 for the nutrient probability, assessed by Kruskal-Wallis tests.

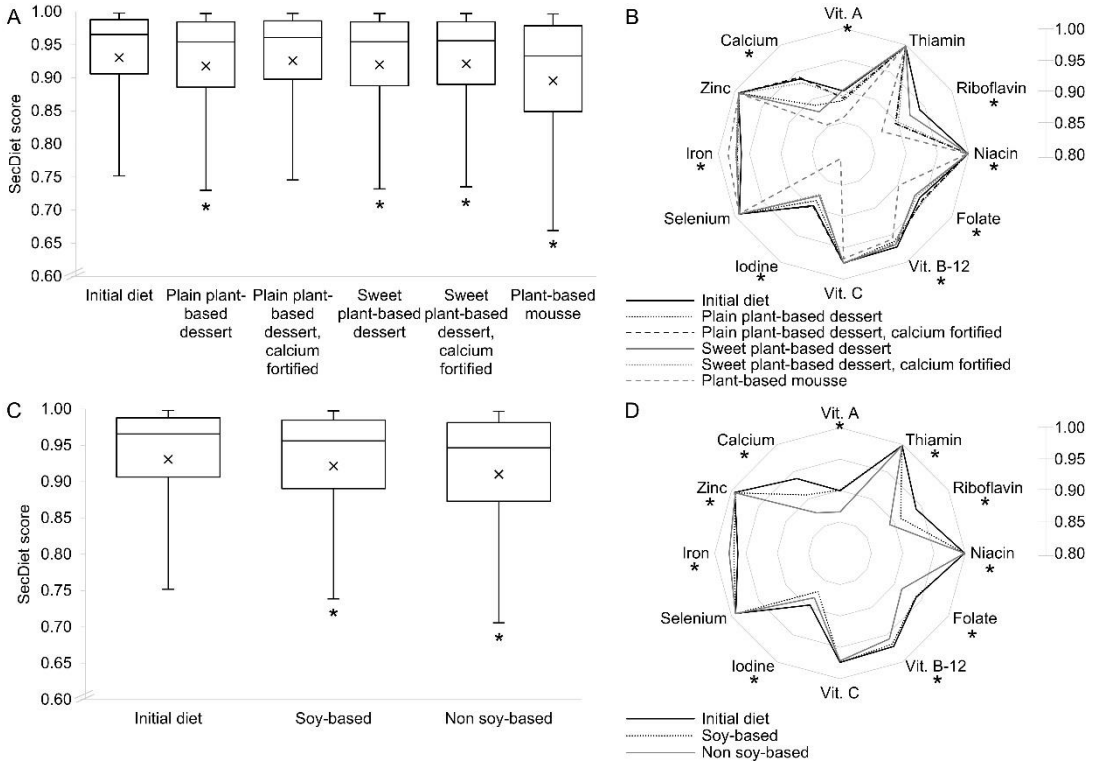


Figure 4. SecDiet score and probabilities for nutrients included in the SecDiet of avoiding overt nutrient deficiency in the initial diets and substitution diets of the "Dairy dessert substitution model" (n=1666). (A) SecDiet score and (B) its constituent probabilities in simulated diets gathered by substitute categories. (C) SecDiet score and (D) its constituent probabilities in simulated diets gathered by the main constituting ingredient of substitutes. (A, C) Lower and upper whiskers are respectively 5th and 95th percentiles; * Significantly different from the initial diet, assessed by Kruskal-Wallis and DSCF tests. (B, D) Values are means, error bars are not presented for the sake of clarity; * *P*(model)<0.05 for the nutrient probability, assessed by Kruskal-Wallis tests.

Supplemental Method 1. Application of the NOVA classification to the INCA3 study.

The NOVA classification (1) was used to assess the degree of food processing of each food product in the INCA3 database. This classification encompasses four groups: 1) unprocessed/minimally processed foods (MPF), 2) processed culinary ingredients, 3) processed foods (PF) and 4) ultra-processed foods (UPF). To discriminate different foods between these categories, the classification takes account of the technical processing technique, the presence of additives and product composition.

For most of the food items consumed, the method of preparation was known and we were able to identify where the food items came from. If the food was homemade, eaten in a restaurant or prepared by an artisan, it was broken down into its ingredients to which the NOVA classification was applied. If the food was industrially processed or came from a fast food restaurant, the NOVA classification was applied directly to the food item. If the method of preparation was unknown, we assigned the processing method most commonly used for this particular food. For each participant we were able to calculate the proportion (%) of total energy intake from MPF, processed culinary ingredients, PF and UPF.

In the present study, only the proportion of total energy intake from UPF was considered.

Supplementary data.

Supplemental Table 1. List of plant-based substitutes categorized by the type of substitute (meat, milk or dairy dessert substitute), its category and the main constituting ingredient.

Type of substitute	Substitute category	Main constituting ingredient of substitute	Substitute name	UPF	Data-base of origin[1]
Meat substitute	Cooked pulses	Pulse-based	Broad bean, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Haricot bean, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Red kidney bean, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Lentil, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Split pea, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Flageolet bean, canned, drained	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Lentil, seasoned, canned, drained	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Haricot bean, canned, drained	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Flageolet bean, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Red kidney bean, canned, drained	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Mung bean, boiled/cooked in water	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Chick pea, canned, drained	No	(2)
Meat substitute	Cooked pulses	Pulse-based	Legume, cooked (average)	No	(2)
Meat substitute	Tofu, tempeh or soy protein	Soy-based	Soy protein, textured, rehydrated	Yes	(3)
Meat substitute	Tofu, tempeh or soy protein	Soy-based	Tofu, plain	No	(3)
Meat substitute	Tofu, tempeh or soy protein	Soy-based	Tempeh	No	(3)
Meat substitute	Plant-based burger	Cereal-based	Cereal burger with cheese (without soybean)	Yes	(3)
Meat substitute	Plant-based burger	Cereal-based	Cereal burger with vegetables (without soybean)	Yes	(3)
Meat substitute	Plant-based burger	Cereal-based	Plant-based burger or steak from wheat (seitan) and vegetables	Yes	(3)
Meat substitute	Plant-based burger	Pulse-based	Plant-based burger or steak from lentil, soybean and vegetables	Yes	(3)
Meat substitute	Plant-based burger	Pulse-based	Plant-based burger from red kidney bean	Yes	(4)
Meat substitute	Plant-based burger	Pulse-based	Plant-based burger from lentil	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Soy burger or vegetable escalope	Yes	(2)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger or steak from soybean and cheese	Yes	(3)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger or steak from soybean and vegetables	Yes	(3)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger or steak from soybean, cheese and vegetables	Yes	(3)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with curry #1	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with curry #2	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with tomatoes and sweet pepper #1	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with tomatoes and sweet pepper #2	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with herbs #1	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with herbs #2	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with vegetables #1	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with vegetables #1	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with tomatoes and basil #1	Yes	(4)
Meat substitute	Plant-based burger	Soy-based	Plant-based burger from soybean with tomatoes and basil #2	Yes	(4)
Meat substitute	Plant-based burger	Soy & Wheat-based	Plant-based burger or steak from wheat and soybean (vegan)	Yes	(3)
Meat substitute	Plant-based burger	Soy & Wheat-based	Plant-based burger or steak from wheat and soybean (not vegan)	Yes	(3)
Meat substitute	Plant-based burger	Soy & Wheat-based	Plant-based burger from cereals and soybean	Yes	(4)
Meat substitute	Plant-based sausage	Cereal-based	Plant-based sausage with wheat or seitan	Yes	(3)
Meat substitute	Plant-based sausage	Cereal-based	Plant-based sausage with wheat	Yes	(4)
Meat substitute	Plant-based sausage	Soy-based	Plant-based sausage with tofu (vegan)	Yes	(3)
Meat substitute	Plant-based sausage	Soy-based	Plant-based sausage with tofu (not vegan)	Yes	(3)
Meat substitute	Plant-based sausage	Soy-based	Plant-based sausage with tofu	Yes	(4)
Meat substitute	Plant-based meat ball or bite	Pulse-based	Falafel	Yes	(2)
Meat substitute	Plant-based meat ball or bite	Pulse-based	Falafel, prepacked	Yes	(3)
Meat substitute	Plant-based meat ball or bite	Soy & Wheat-based	Soy and wheat burger or bite (vegan)	Yes	(3)
Meat substitute	Plant-based meat ball or bite	Soy & Wheat-based	Soy and wheat burger or bite (not vegan)	Yes	(3)
Meat substitute	Plant-based meat ball or bite	Soy & Wheat-based	Plant-based ball with wheat and/or soybean	Yes	(3)
Meat substitute	Plant-based breaded food	Cereal-based	Wheat-based nuggets (wo soybean)	Yes	(3)
Meat substitute	Plant-based breaded food	Soy & Wheat-based	Soybean and wheat-based nuggets (not vegan)	Yes	(3)
Meat substitute	Plant-based breaded food	Soy & Wheat-based	Soybean and wheat-based nuggets (vegan)	Yes	(3)
Meat substitute	Plant-based breaded food	Soy & Wheat-based	Schnitzel, soybean and wheat-based (not vegan)	Yes	(3)
Meat substitute	Plant-based breaded food	Soy & Wheat-based	Schnitzel, soybean and wheat-based (vegan)	Yes	(3)
Meat substitute	Plant-based breaded food	Soy & Wheat-based	Schnitzel, soybean, wheat and cheese-based, cordon bleu-style	Yes	(3)
Milk substitute	Plain plant-based milk	Cereal-based	Oat drink, plain	Yes	(4)
Milk substitute	Plain plant-based milk	Nut-based	Almond drink not sweet, not fortified, prepacked #1	Yes	(2)
Milk substitute	Plain plant-based milk	Nut-based	Almond drink not sweet, not fortified, prepacked #2	Yes	(3)
Milk substitute	Plain plant-based milk	Nut-based	Coconut-based drink, plain, prepacked	Yes	(3)

Supplementary data.

Milk substitute	Plain plant-based milk	Nut-based	Almond drink, plain	Yes	(4)
Milk substitute	Plain plant-based milk	Soy-based	Soy drink, plain, prepacked	Yes	(2)
Milk substitute	Plain plant-based milk	Soy-based	Soy drink, plain	Yes	(4)
Milk substitute	Plain plant-based milk, calcium-fortified	Nut-based	Almond-based drink, sweet, fortified with calcium, prepacked	Yes	(3)
Milk substitute	Plain plant-based milk, calcium-fortified	Soy-based	Soy drink, plain, fortified with calcium, prepacked	Yes	(2)
Milk substitute	Plain plant-based milk, calcium-fortified	Soy-based	Soy drink, plain, fortified with calcium	Yes	(4)
Milk substitute	Sweet plant-based milk	Cereal-based	Spelt drink, plain	Yes	(4)
Milk substitute	Sweet plant-based milk	Cereal-based	Rice drink, plain	Yes	(4)
Milk substitute	Sweet plant-based milk	Nut-based	Chestnut drink, plain	Yes	(4)
Milk substitute	Sweet plant-based milk	Soy-based	Soy drink, sweet, flavored, with sugar, prepacked	Yes	(2)
Milk substitute	Sweet plant-based milk, calcium-fortified	Nut-based	Chestnut-based drink, plain, prepacked	Yes	(3)
Milk substitute	Sweet plant-based milk, calcium-fortified	Soy-based	Soy drink, flavored, fortified with calcium	Yes	(4)
Dairy dessert substitute	Plain plant-based dessert	Soy-based	Soy dessert, plain, not fortified, prepacked	Yes	(3)
Dairy dessert substitute	Plain plant-based dessert	Soy-based	Soy dessert, plain	Yes	(4)
Dairy dessert substitute	Plain plant-based dessert, calcium-fortified	Soy-based	Soy dessert, plain, prepacked	Yes	(2)
Dairy dessert substitute	Plain plant-based dessert, calcium-fortified	Soy-based	Soy dessert, plain, fortified with calcium, prepacked	Yes	(3)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, w fruits, sweet, not fortified, prepacked	Yes	(3)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, flavored, sweet, not fortified, prepacked	Yes	(3)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, with fruits #1	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, with fruits #2	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, flavored #1	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, flavored #2	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Soy-based	Soy dessert, flavored #3	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Non soy-based	Plant-based dessert, without soy #1	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Non soy-based	Plant-based dessert, without soy #2	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert	Non soy-based	Plant-based dessert (almond, oat, hemp, coconut, rice), flavored, sweet, not fortified, prepacked	Yes	(3)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, w fruits, sweet, fortified with calcium, prepacked #1	Yes	(2)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, w fruits, sweet, fortified with calcium, prepacked #2	Yes	(3)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, flavored, sweet, fortified with calcium, prepacked #1	Yes	(2)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, flavored, sweet, fortified with calcium, prepacked #2	Yes	(3)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, with fruits #3	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, with fruits #4	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Soy-based	Soy dessert, flavored #4	Yes	(4)
Dairy dessert substitute	Sweet plant-based dessert, calcium fortified	Non soy-based	Plant-based dessert without soybean (coconut, rice), with fruits, sweet, fortified with calcium, prepacked	Yes	(3)
Dairy dessert substitute	Plant-based mousse	Soy-based	Soy mousse, chocolate, pant-based	Yes	(4)
Dairy dessert substitute	Plant-based mousse	Non soy-based	Mousse, chocolate, plant-based, prepacked	Yes	(3)

1Three nutritional composition databases were used to complete this list: CIQUAL French composition table version 2016 (2), CIQUAL French composition table version 2020 (3) and the NutriNet-Santé Study Food composition database (4).
UPF, Ultra-processed foods

Supplemental Table 2. Reference values of the PANDiet scoring system, version 3.2 (5–7).

PANDiet score		
Average of Adequacy and Moderation subscores		
Adequacy subscore		
Nutrient	**Reference value (/day)(7)**	**Variability**
Protein	0.66 or 0.8 g/kg bw	12.5%
LA	3.08% EIEA	15%
ALA	0.769% EIEA	15%
DHA	0.192 g	15%
EPA + DHA	0.385 g	15%
Fiber	23 g	15%
Vitamin A	580 or 490 µg	15%
Thiamin	0.3 mg/1000 kcal	20%
Riboflavin	1.3 mg	10%
Niacin	5.44 mg NE/1000kcal	10%
Pantothenic acid	3.33 or 2.78 mg	40%
Vitamin B-6	1.5 or 1.3 mg	10%
Folate	250 µg	15%
Vitamin B-12	3.33 µg	10%
Vitamin C	90 mg	10%
Vitamin D	10 µg	25%
Vitamin E	5.26 or 4.74 mg	45%
Calcium	860 (<= 24 y.o) or 750 mg (>24 y.o.)	15% or 13%
Copper	0.86 or 0.68 mg	60%
Iodine	107 µg	20%
Bioavailable iron	See supplemental method 1 in de Gavelle et al. (6)	
Magnesium	224 or 176 mg	35%
Manganese	1.89 or 1.56 mg	40%
Phosphorus	Calcium (mmol) / 1.65 *Cf.* phosphorus section in de Gavelle et al. (6)	7.5% + CV Calcium (mg)
Potassium	2692 mg	15%
Selenium	54 µg	15%
Bioavailable zinc	0.642 + 0.038 x bw	10%

Moderation subscore		
Nutrient	**Reference value (/day)(7)**	**Variability**
Protein	2.2 g/kg bw	12.5%
Total fat	44% EIEA	5%
SFA	12% EIEA	15%
Carbohydrates	60.5% EIEA	5%
Sugars	100 g	15%
Sodium	3200 mg	15%

Tolerable Upper Intake Limits	
Retinol	3000 µg
Niacin	900 mg
Vitamin B-6	25 mg
Folate	1170 µg
Vitamin D	100 µg
Vitamin E	300 mg
Calcium	2500 mg
Copper	10 mg
Iodine	600 µg
Dissociable magnesium	250 mg
Selenium	300 µg
Zinc	25 mg

ALA, alpha-linolenic acid; bw, body weight; CV, coefficient of variation; DHA, docosahexaenoic acid; EIEA, energy intake excluding alcohol; EPA, eicosapentaenoic acid; LA, linoleic acid; NE, niacin equivalent; SFA, saturated fatty acids.

The PANDiet score is expressed as the average of an adequacy subscore (AS – accounting for 27 nutrients) and a moderation subscore (MS – accounting for six nutrients, plus 12 potential penalty values). DHA and EPA+DHA are weighted by a factor of 1/2 as DHA is present twice. Niacin equivalents are calculated as the sum of dietary niacin and 1/60 dietary tryptophan. The upper reference value for sugars excludes lactose. The tolerable upper intake limit for vitamin A concerns retinol only. The PANDiet 3.2 version is based on the dietary reference intake from the ANSES opinion (7) and complete construction of the score has been described elsewhere (5).

Compared to the PANDiet 3.1 version, the references values have been updated for vitamin A, pantothenic acid, vitamin E, copper, magnesium, manganese and sodium in order to take account of the latest ANSES opinion (7).

For vitamin A, the average requirement for men has been readjusted to 580 µg/day rather than 570 µg/day. For pantothenic acid, vitamin E, copper, magnesium and manganese an adequate intake has been defined based on recent observed intake from the INCA3 survey. Then, to calculate PANDiet, a pseudo average intake has been derived by considering the coefficient of variation of intake in the French population. For sodium, an upper limit intake has been defined by ANSES at 2300mg/day, which is based on the sodium Chronic Disease Risk Reduction Intake (CDRR) defined by the HMD (8). From a literature review, the HMD has determined that with a sodium intake of between

2300mg/day and 4100mg/day, any reduction in sodium intake would lead to a reduced risk of chronic disease. From this, we hypothesized that 2.5% of the population would be at a higher risk of chronic disease with a sodium intake of 2300mg/day, and 97.5% of the population would be at a higher risk of chronic disease with a sodium intake of 4100 mg/day. We could then derive a risk curve and define a mean intake at which 50% of the population would be at higher risk, which is 3200 mg and a CV of 15%.

For zinc, the calculation of bioavailable zinc was updated and the following mathematical model was used to calculate bioavailable zinc from dietary zinc and phytate intakes (9):

$$TAZ = 0.5 \times \left(0.033 \times \left(1 + \frac{TDP}{0.68}\right) + 0.091 + TDZ - \sqrt{\left(0.033 \times \left(1 + \frac{TDP}{0.68}\right) + 0.091 + TDZ\right)^2 - 4 \times 0.091 \times TDZ} \right)$$

TAZ: total absorbed zinc (mmol), TDZ: total dietary zinc (mmol) and TDP: total dietary phytate (mmol).

Supplemental Table 3. Nutrients included as components in the SecDiet score and associated deficiency and threshold values.

Nutrients were included in the SecDiet score if clinical signs of deficiency might appear because of insufficient intakes. The threshold value (DT) was defined as the minimal intake below which there is a risk of appearance of a deficiency. The reference value used to calculate the probability of adequacy of the average deficiency threshold (aDT), which corresponds to the intake at which 50% of the population is at risk of nutritional deficiency. The complete construction of the score has been fully described elsewhere (10).

Nutrient	Deficiency	Threshold (DT)	CV	50% of risk (aDT)
Vitamin A(11)	Xerophtalmia	300 µg RE or 270 µg RE	15%	231 µg RE or 208 µg RE
Thiamin(12)	Beriberi	0.18 mg/1000kcal	20%	0.13 mg/1000kcal
Riboflavin(12)	Ariboflavinosis	1.0 mg	10%	0.83 mg
Niacin(12)	Pellagra	4.35 mg NE/1000kcal	10%	3.63 NE/1000kcal
Folate(12)	Megaloblastic anemia	175 µg	15%	135 µg
Vitamin B-12(13)	Megaloblastic anemia	1 µg	15%	0.77 µg
Vitamin C(11)	Scurvy	10 mg	10%	8.3 mg
Iodine*(12)	Goiter	150 µg	20%	107 µg
Selenium(14)	Keshan disease	21 µg or 16 µg	15%	16.2 µg or 12.3 µg
Bioavailable iron*(15)	Anemia	1.74 mg†	40%	0.95 mg†
Bioavailable zinc(16)	Zinc deficiency	1.6 mg or 1.3 mg	15%	1.23mg or 1.0 mg
Calcium(17–19)	Fracture risk (long-term)	500 mg	15%	385 mg

DT, deficiency threshold; CV, coefficient of variation of the individual threshold; aDT, average deficiency threshold; RE, retinol equivalent; NE, niacin equivalent.

* These thresholds parameters were then further corrected to calibrate the estimated average risk using figures for the national prevalence of goiter for iodine and anemia for iron. For iodine, the recalibrated DT was set at 100 µg and the aDT at 71.3 µg. For iron, the recalibrated DT was set at 0.70mg and the aDT at 0.38 (see (10))

† This value applies to men and non-menstruating women. Requirements for menstruating women were estimated by considering menstrual losses using a Monte-Carlo simulation (see (10)).

Supplemental Table 4. PANDiet, AS, MS and probabilities of adequacies for the initial diet and differences observed in different scenarios of substitutions of meat items with meat substitutes according to the substitute's category in French adults (n=1949)[1].

		MEAT SUBSTITUTION MODEL						
		Simulation of substitution of meat items with meat substitute according to the substitute's category[3]						
	Initial diet[2]	Cooked pulses	Tofu, tempeh or soy protein	Plant-based burgers	Plant-based sausages	Plant-based meat balls or slices	Plant-based breaded foods	P[4] (model)
PANDiet score (0-100)	68.33 (67.97, 68.69)	+0.04 (-0.54, 0.61)	+1.58 (1.01, 2.16)*	+0.34 (-0.24, 0.92)	-0.60 (-1.18, -0.02)*	+0.46 (-0.11, 1.04)	+0.25 (-0.33, 0.83)	<0.0001
Adequacy Sub-score (AS) (0-100)	63.66 (62.84, 64.47)	-1.03 (-2.34, 0.27)	+0.88 (-0.43, 2.19)	+0.13 (-1.17, 1.44)	-1.46 (-2.77, -0.16)*	-0.10 (-1.4, 1.21)	-2.02 (-3.33, -0.71)*	<0.0001
Probabilities of adequacy for AS components (0-1)								
Protein	0.85 (0.83, 0.86)	-0.11 (-0.14, -0.09)*	-0.04 (-0.06, -0.01)*	-0.09 (-0.11, -0.06)*	-0.04 (-0.07, -0.02)*	-0.08 (-0.11, -0.05)*	-0.09 (-0.11, -0.06)*	<0.0001
LA	0.46 (0.44, 0.47)	-0.05 (-0.08, -0.02)*	+0.24 (0.22, 0.27)*	+0.22 (0.19, 0.24)*	+0.30 (0.27, 0.33)*	+0.26 (0.23, 0.29)*	+0.33 (0.30, 0.35)*	<0.0001
ALA	0.12 (0.11, 0.14)	+0.03 (0.01, 0.05)*	+0.12 (0.10, 0.15)*	+0.07 (0.04, 0.09)*	+0.06 (0.04, 0.08)*	+0.04 (0.02, 0.07)*	+0.04 (0.02, 0.06)*	<0.0001
DHA	0.22 (0.20, 0.24)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	-0.01 (-0.04, 0.02)	0.00 (-0.04, 0.03)	-0.01 (-0.04, 0.02)	0.9426
EPA+DHA	0.20 (0.18, 0.21)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	-0.01 (-0.03, 0.02)	-0.01 (-0.03, 0.02)	-0.01 (-0.04, 0.02)	0.9230
Fiber	0.34 (0.32, 0.36)	+0.26 (0.23, 0.29)*	+0.17 (0.14, 0.20)*	+0.19 (0.16, 0.22)*	+0.06 (0.03, 0.09)*	+0.22 (0.19, 0.25)*	+0.13 (0.10, 0.16)*	<0.0001
Vitamin A	0.49 (0.47, 0.51)	+0.01 (-0.03, 0.04)	-0.01 (-0.04, 0.03)	+0.01 (-0.03, 0.04)	-0.01 (-0.04, 0.03)	-0.02 (-0.05, 0.01)	-0.04 (-0.07, 0.00)*	0.0006
Thiamine	0.97 (0.96, 0.97)	0.00 (-0.01, 0.01)	-0.02 (-0.03, -0.01)*	0.00 (-0.01, 0.01)	-0.02 (-0.03, -0.01)*	-0.01 (-0.02, 0.00)*	-0.02 (-0.02, -0.01)*	<0.0001
Riboflavin	0.74 (0.72, 0.76)	-0.05 (-0.08, -0.01)*	-0.06 (-0.09, -0.02)*	-0.07 (-0.10, -0.04)*	-0.07 (-0.10, -0.03)*	-0.08 (-0.11, -0.05)*	-0.10 (-0.13, -0.07)*	<0.0001
Niacin	0.998 (0.997, 0.998)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	-0.002 (-0.003, 0.00)*	-0.003 (-0.004, -0.001)*	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	<0.0001
Pantothenic acid	0.86 (0.85, 0.87)	-0.03 (-0.05, -0.01)*	-0.02 (-0.04, 0.00)*	-0.04 (-0.06, -0.02)*	-0.06 (-0.08, -0.05)*	-0.04 (-0.06, -0.02)*	-0.06 (-0.08, -0.05)*	<0.0001
Vitamin B-6	0.66 (0.64, 0.68)	-0.13 (-0.16, -0.09)*	-0.15 (-0.18, -0.12)*	-0.16 (-0.20, -0.13)*	-0.21 (-0.25, -0.18)*	-0.18 (-0.21, -0.15)*	-0.25 (-0.28, -0.22)*	<0.0001
Folate	0.63 (0.62, 0.65)	+0.16 (0.13, 0.19)*	+0.09 (0.06, 0.12)*	+0.1 (0.08, 0.13)*	+0.02 (0.00, 0.05)	+0.11 (0.08, 0.14)*	+0.01 (-0.01, 0.04)	<0.0001
Vitamin B-12	0.62 (0.6, 0.64)	-0.22 (-0.25, -0.18)*	-0.23 (-0.26, -0.20)*	-0.23 (-0.26, -0.20)*	-0.24 (-0.28, -0.21)*	-0.24 (-0.27, -0.21)*	-0.25 (-0.29, -0.22)*	<0.0001
Vitamin C	0.43 (0.41, 0.46)	+0.02 (-0.01, 0.06)	0 (-0.03, 0.04)	+0.01 (-0.02, 0.05)	0.00 (-0.04, 0.03)	-0.01 (-0.04, 0.03)	-0.02 (-0.06, 0.02)	0.0190
Vitamin D	0.03 (0.03, 0.04)	0.00 (-0.01, 0.01)	0.00 (-0.01, 0.01)	0.00 (-0.01, 0.01)	0.00 (-0.01, 0.00)	0.00 (-0.01, 0.01)	-0.01 (-0.01, 0.00)	0.3876
Vitamin E	0.82 (0.81, 0.83)	+0.01 (0.00, 0.03)	+0.03 (0.01, 0.04)*	+0.05 (0.03, 0.06)*	+0.11 (0.09, 0.12)*	+0.08 (0.07, 0.10)*	+0.10 (0.09, 0.12)*	<0.0001
Iodine	0.69 (0.67, 0.70)	+0.01 (-0.02, 0.04)	+0.04 (0.01, 0.06)*	+0.02 (-0.01, 0.04)	0.00 (-0.03, 0.03)	+0.01 (-0.02, 0.04)	0.00 (-0.03, 0.03)	0.0002
Magnesium	0.86 (0.85, 0.87)	+0.02 (0.01, 0.04)*	+0.06 (0.05, 0.08)*	+0.06 (0.04, 0.07)*	+0.02 (0.00, 0.03)*	+0.04 (0.02, 0.05)*	+0.01 (0.00, 0.02)	<0.0001
Phosphorus	0.97 (0.97, 0.98)	-0.01 (-0.01, 0.00)	0.00 (-0.01, 0.00)	0.00 (-0.01, 0.00)	-0.01 (-0.01, 0.00)*	0.00 (-0.01, 0.00)	-0.01 (-0.01, 0.00)*	0.0054
Potassium	0.62 (0.6, 0.64)	+0.01 (-0.02, 0.04)	+0.03 (0.00, 0.06)*	0.00 (-0.03, 0.03)	-0.07 (-0.10, -0.04)*	+0.05 (0.01, 0.08)*	-0.02 (-0.05, 0.01)	<0.0001
Selenium	0.93 (0.93, 0.94)	-0.01 (-0.02, 0.00)	0.00 (-0.01, 0.02)	0.00 (-0.02, 0.01)	0.00 (-0.01, 0.02)	0.00 (-0.01, 0.02)	-0.01 (-0.02, 0.01)	0.0035
Zinc	0.31 (0.3, 0.33)	-0.20 (-0.22, -0.18)*	-0.14 (-0.16, -0.12)*	-0.15 (-0.17, -0.13)*	-0.18 (-0.20, -0.16)*	-0.17 (-0.19, -0.15)*	-0.20 (-0.22, -0.17)*	<0.0001
Copper	0.86 (0.85, 0.87)	+0.03 (0.02, 0.05)*	+0.06 (0.05, 0.08)*	+0.04 (0.03, 0.05)*	+0.02 (0.01, 0.04)*	+0.04 (0.03, 0.05)*	+0.02 (0.01, 0.03)*	<0.0001
Manganese	0.87 (0.86, 0.88)	+0.05 (0.04, 0.06)*	+0.08 (0.07, 0.09)*	+0.08 (0.07, 0.09)*	+0.07 (0.06, 0.08)*	+0.07 (0.06, 0.08)*	+0.06 (0.04, 0.07)*	<0.0001
Calcium	0.60 (0.58, 0.62)	+0.06 (0.03, 0.09)*	+0.09 (0.05, 0.12)*	+0.08 (0.04, 0.11)*	+0.06 (0.03, 0.09)*	+0.05 (0.01, 0.08)*	+0.03 (0.00, 0.06)	<0.0001
Iron	0.61 (0.6, 0.63)	-0.16 (-0.18, -0.13)*	-0.13 (-0.16, -0.11)*	-0.12 (-0.14, -0.09)*	-0.17 (-0.20, -0.15)*	-0.16 (-0.18, -0.13)*	-0.18 (-0.21, -0.16)*	<0.0001
Moderation Sub-score (MS) (0-100)	73.01 (72.29, 73.72)	+1.11 (-0.03, 2.25)	+2.29 (1.15, 3.43)*	+0.55 (-0.60, 1.69)	+0.27 (-0.87, 1.41)	+1.02 (-0.12, 2.16)	+2.51 (1.37, 3.66)*	<0.0001
Probabilities of adequacy for MS components (0-1)								
Carbohydrates	0.96 (0.95, 0.96)	-0.07 (-0.08, -0.06)*	-0.02 (-0.03, -0.01)*	-0.03 (-0.05, -0.02)*	0.00 (-0.02, 0.01)	-0.01 (-0.03, 0.00)*	-0.01 (-0.02, 0.00)	<0.0001
Protein	0.96 (0.95, 0.96)	+0.03 (0.02, 0.04)*	+0.01 (0.01, 0.02)*	+0.02 (0.01, 0.03)*	+0.01 (0.00, 0.02)*	+0.02 (0.01, 0.03)*	+0.02 (0.02, 0.03)*	<0.0001
Total fat	0.90 (0.89, 0.91)	+0.04 (0.02, 0.05)*	+0.02 (0.01, 0.04)*	+0.02 (0.00, 0.03)*	-0.01 (-0.02, 0.01)	+0.01 (0.00, 0.03)	+0.01 (-0.01, 0.02)	<0.0001
SFA	0.30 (0.28, 0.32)	+0.10 (0.07, 0.13)*	+0.10 (0.07, 0.13)*	+0.10 (0.07, 0.13)*	+0.10 (0.07, 0.13)*	+0.12 (0.09, 0.15)*	+0.14 (0.11, 0.17)*	<0.0001
Sodium	0.57 (0.55, 0.59)	-0.01 (-0.04, 0.03)	+0.03 (0.00, 0.06)	-0.07 (-0.10, -0.04)*	-0.10 (-0.13, -0.06)*	-0.08 (-0.11, -0.05)*	-0.03 (-0.07, 0.00)*	<0.0001
Sugars without lactose	0.71 (0.69, 0.73)	-0.03 (-0.06, 0.00)	-0.02 (-0.05, 0.01)	-0.02 (-0.05, 0.01)	0.00 (-0.03, 0.03)	-0.01 (-0.04, 0.02)	+0.01 (-0.02, 0.04)	0.0005

[1] Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only meat consumers where selected (n=1949). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated fatty acids.
[2] Values are means with a 95% confidence interval.
[3] Values are differences in means between the simulated diet and the initial diet with a 95% confidence interval of the difference. * Mean of the simulated diet significantly different from the mean of the initial diet.
[4] *P* for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplementary data.

Supplemental Table 5. PANDiet, AS, MS and probabilities of adequacies for the initial diet and differences observed in different scenarios of substitutions of meat items with meat substitutes according to the substitute's main constituting ingredient in French adults (n=1949)[1].

		MEAT SUBSTITUTION MODEL				
	Initial diet[2]	Simulation of substitution of meat items with meat substitute according to the substitute's main constituting ingredient[3]				P[4] (model)
		Soy-based substitutes	Cereal-based substitutes	Pulse-based substitutes	Soy & Wheat-based substitutes	
PANDiet score (0-100)	68.33 (67.99, 68.68)	+0.57 (0.04, 1.10)*	-0.72 (-1.25, -0.19)*	+0.09 (-0.44, 0.63)	+0.45 (-0.09, 0.98)	<0.0001
Adequacy Sub-score (AS) (0-100)	63.66 (62.87, 64.44)	+0.57 (-0.64, 1.79)	-3.08 (-4.29, -1.86)*	-0.86 (-2.08, 0.36)	-0.51 (-1.73, 0.70)	<0.0001
Probabilities of adequacy for AS components (0-1)						
Protein	0.85 (0.83, 0.86)	-0.07 (-0.09, -0.04)*	-0.09 (-0.11, -0.06)*	-0.12 (-0.14, -0.09)*	-0.07 (-0.09, -0.04)*	<0.0001
LA	0.46 (0.44, 0.47)	+0.27 (0.25, 0.30)*	+0.18 (0.16, 0.21)*	+0.01 (-0.01, 0.04)	+0.27 (0.25, 0.30)*	<0.0001
ALA	0.12 (0.11, 0.14)	+0.09 (0.07, 0.11)*	-0.01 (-0.03, 0.02)	+0.04 (0.02, 0.06)*	+0.05 (0.03, 0.07)*	<0.0001
DHA	0.22 (0.21, 0.24)	0.00 (-0.03, 0.03)	-0.01 (-0.04, 0.02)	0.00 (-0.03, 0.03)	-0.01 (-0.03, 0.02)	0.9152
EPA+DHA	0.20 (0.18, 0.21)	0.00 (-0.03, 0.02)	-0.01 (-0.04, 0.02)	0.00 (-0.03, 0.03)	-0.01 (-0.03, 0.02)	0.8685
Fiber	0.34 (0.32, 0.36)	+0.17 (0.15, 0.20)*	+0.10 (0.07, 0.13)*	+0.25 (0.22, 0.28)*	+0.17 (0.14, 0.20)*	<0.0001
Vitamin A	0.49 (0.47, 0.51)	+0.01 (-0.02, 0.04)	-0.03 (-0.06, 0.00)	+0.01 (-0.03, 0.04)	-0.02 (-0.05, 0.01)	0.0034
Thiamine	0.97 (0.96, 0.97)	0.00 (-0.01, 0.00)	-0.02 (-0.02, -0.01)*	0.00 (-0.01, 0.01)	-0.01 (-0.02, 0.00)*	<0.0001
Riboflavin	0.74 (0.72, 0.76)	-0.06 (-0.09, -0.03)*	-0.10 (-0.13, -0.07)*	-0.06 (-0.09, -0.03)*	-0.08 (-0.11, -0.05)*	<0.0001
Niacin	0.998 (0.997, 0.998)	-0.001 (-0.002, 0.00)*	-0.002 (-0.003, -0.001)*	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	<0.0001
Pantothenic acid	0.86 (0.85, 0.87)	-0.04 (-0.06, -0.02)*	-0.06 (-0.08, -0.04)*	-0.03 (-0.05, -0.02)*	-0.05 (-0.07, -0.03)*	<0.0001
Vitamin B-6	0.66 (0.64, 0.68)	-0.16 (-0.19, -0.13)*	-0.24 (-0.27, -0.21)*	-0.14 (-0.17, -0.11)*	-0.21 (-0.24, -0.18)*	<0.0001
Folate	0.63 (0.62, 0.65)	+0.10 (0.07, 0.12)*	+0.01 (-0.02, 0.04)	+0.15 (0.13, 0.18)*	+0.07 (0.05, 0.10)*	<0.0001
Vitamin B-12	0.62 (0.60, 0.64)	-0.23 (-0.26, -0.20)*	-0.25 (-0.28, -0.22)*	-0.22 (-0.26, -0.19)*	-0.24 (-0.27, -0.21)*	<0.0001
Vitamin C	0.43 (0.41, 0.45)	+0.02 (-0.02, 0.05)	-0.02 (-0.05, 0.01)	+0.02 (-0.02, 0.05)	-0.01 (-0.04, 0.02)	0.0099
Vitamin D	0.03 (0.03, 0.04)	0.00 (-0.01, 0.01)	-0.01 (-0.01, 0.00)	0.00 (-0.01, 0.01)	0 (-0.01, 0.00)	0.3627
Vitamin E	0.82 (0.81, 0.83)	+0.04 (0.02, 0.05)*	+0.10 (0.09, 0.11)*	+0.03 (0.02, 0.05)*	+0.09 (0.07, 0.10)*	<0.0001
Iodine	0.69 (0.67, 0.70)	+0.01 (-0.02, 0.03)	0.00 (-0.03, 0.02)	+0.01 (-0.01, 0.04)	+0.03 (0.00, 0.05)*	0.0038
Magnesium	0.86 (0.85, 0.87)	+0.06 (0.05, 0.08)*	0.00 (-0.01, 0.02)	+0.03 (0.01, 0.04)*	+0.04 (0.02, 0.05)*	<0.0001
Phosphorus	0.97 (0.97, 0.98)	0.00 (-0.01, 0.00)	-0.01 (-0.01, 0.00)*	-0.01 (-0.01, 0.00)	0.00 (-0.01, 0.00)	0.0351
Potassium	0.62 (0.60, 0.64)	0.00 (-0.03, 0.03)	-0.06 (-0.09, -0.03)*	+0.01 (-0.02, 0.04)	+0.02 (-0.01, 0.05)	<0.0001
Selenium	0.93 (0.93, 0.94)	0.00 (-0.01, 0.01)	0.00 (-0.01, 0.01)	-0.01 (-0.02, 0.00)	0.00 (-0.01, 0.01)	0.4705
Zinc	0.31 (0.30, 0.33)	-0.14 (-0.16, -0.12)*	-0.19 (-0.21, -0.17)*	-0.20 (-0.22, -0.18)*	-0.18 (-0.20, -0.16)*	<0.0001
Copper	0.86 (0.85, 0.87)	+0.04 (0.03, 0.06)*	+0.01 (0.00, 0.03)*	+0.04 (0.02, 0.05)*	+0.04 (0.02, 0.05)*	<0.0001
Manganese	0.87 (0.86, 0.88)	+0.08 (0.07, 0.09)*	+0.06 (0.05, 0.08)*	+0.06 (0.04, 0.07)*	+0.07 (0.06, 0.08)*	<0.0001
Calcium	0.60 (0.58, 0.62)	+0.09 (0.06, 0.12)*	+0.01 (-0.02, 0.04)	+0.05 (0.02, 0.08)*	+0.05 (0.02, 0.08)*	<0.0001
Iron	0.61 (0.60, 0.63)	-0.12 (-0.14, -0.09)*	-0.20 (-0.23, -0.18)*	-0.15 (-0.18, -0.13)*	-0.15 (-0.17, -0.13)*	<0.0001
Moderation Sub-score (MS) (0-100)	73.01 (72.33, 73.69)	+0.56 (-0.49, 1.61)	+1.63 (0.58, 2.68)*	+1.05 (0.00, 2.10)	+1.41 (0.35, 2.46)*	0.0001
Probabilities of adequacy for MS components (0-1)						
Carbohydrates	0.96 (0.95, 0.96)	-0.02 (-0.04, -0.01)*	-0.02 (-0.04, -0.01)*	-0.06 (-0.08, -0.05)*	-0.01 (-0.02, 0.00)	<0.0001
Protein	0.96 (0.95, 0.96)	+0.02 (0.01, 0.03)*	+0.02 (0.01, 0.03)*	+0.03 (0.02, 0.03)*	+0.02 (0.01, 0.03)*	<0.0001
Total fat	0.90 (0.90, 0.91)	+0.01 (0.00, 0.02)	+0.02 (0.01, 0.03)*	+0.03 (0.02, 0.05)*	+0.01 (0.00, 0.02)	<0.0001
SFA	0.30 (0.29, 0.32)	+0.10 (0.07, 0.12)*	+0.12 (0.09, 0.15)*	+0.10 (0.07, 0.13)*	+0.12 (0.09, 0.15)*	<0.0001
Sodium	0.57 (0.55, 0.59)	-0.07 (-0.10, -0.04)*	-0.05 (-0.08, -0.02)*	-0.02 (-0.05, 0.01)	-0.07 (-0.10, -0.04)*	<0.0001
Sugars without lactose	0.71 (0.69, 0.73)	-0.02 (-0.04, 0.01)	0.00 (-0.03, 0.03)	-0.03 (-0.06, 0.00)	0.00 (-0.03, 0.03)	0.0229

[1] Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only meat consumers where selected (n=1949). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated fatty acids.
[2] Values are means with a 95% confidence interval.
[3] Values are differences in means between the simulated diet and the initial diet with a 95% confidence interval of the difference. * Mean of the simulated diet significantly different from the mean of the initial diet.
[4] P for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplemental Table 6. PANDiet, AS, MS and probabilities of adequacies of the initial diet and differences observed in different scenarios of substitutions of milk items with milk substitutes according to the substitute's category in French adults (n=837)[1].

	MILK SUBSTITUTION MODEL					
		Simulation of substitution of milk items with milk substitute according to the substitute's category[3]				
	Initial diet[2]	Plain plant-based milks	Plain plant-based milks, calcium-fortified	Sweet plant-based milks	Sweet plant-based milks, calcium-fortified	P[4] (model)
PANDiet score (0-100)	69.04 (68.51, 69.57)	-0.56 (-1.38, 0.26)	-0.24 (-1.06, 0.58)	-1.19 (-2.01, -0.37)*	-0.23 (-1.05, 0.59)	0.0005
Adequacy Sub-score (AS) (0-100)	64.81 (63.59, 66.02)	-0.7 (-2.57, 1.17)	-0.17 (-2.04, 1.71)	-1.89 (-3.76, -0.02)*	+0.19 (-1.68, 2.06)	0.0133
Probabilities of adequacy for AS components (0-1)						
Protein	0.85 (0.83, 0.87)	-0.02 (-0.06, 0.01)	-0.01 (-0.05, 0.02)	-0.04 (-0.07, -0.01)*	-0.04 (-0.07, 0)*	0.0028
LA	0.43 (0.41, 0.46)	+0.14 (0.10, 0.19)*	+0.17 (0.13, 0.22)*	+0.15 (0.11, 0.19)*	+0.21 (0.16, 0.25)*	<0.0001
ALA	0.11 (0.09, 0.13)	+0.04 (0.02, 0.07)*	+0.04 (0.01, 0.06)*	+0.01 (-0.02, 0.04)	+0.01 (-0.01, 0.04)	<0.0001
DHA	0.22 (0.19, 0.25)	0.00 (-0.04, 0.05)	0.00 (-0.04, 0.05)	0.00 (-0.05, 0.04)	0 (-0.04, 0.04)	0.9928
EPA+DHA	0.19 (0.16, 0.22)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0 (-0.04, 0.04)	0.9965
Fiber	0.32 (0.30, 0.35)	+0.05 (0.01, 0.10)*	+0.04 (-0.01, 0.08)	+0.02 (-0.03, 0.06)	+0.02 (-0.02, 0.07)	0.0076
Vitamin A	0.49 (0.46, 0.52)	0.00 (-0.05, 0.04)	0.00 (-0.05, 0.05)	-0.04 (-0.09, 0.01)	-0.01 (-0.05, 0.04)	0.0734
Thiamine	0.98 (0.97, 0.98)	-0.01 (-0.02, 0.00)*	-0.01 (-0.02, 0.00)*	-0.01 (-0.02, 0.00)	-0.01 (-0.02, 0.00)	0.0111
Riboflavin	0.80 (0.77, 0.83)	-0.09 (-0.13, -0.05)*	-0.09 (-0.13, -0.05)*	-0.14 (-0.18, -0.09)*	-0.07 (-0.11, -0.03)*	<0.0001
Niacin	0.998 (0.997, 0.999)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.8273
Pantothenic acid	0.89 (0.87, 0.90)	-0.04 (-0.06, -0.02)*	-0.05 (-0.07, -0.03)*	-0.04 (-0.07, -0.02)*	-0.05 (-0.07, -0.02)*	<0.0001
Vitamin B-6	0.66 (0.63, 0.69)	-0.01 (-0.06, 0.03)	-0.02 (-0.06, 0.03)	0.00 (-0.05, 0.04)	-0.02 (-0.07, 0.02)	0.6138
Folate	0.65 (0.62, 0.68)	0.00 (-0.04, 0.05)	+0.01 (-0.03, 0.06)	-0.03 (-0.07, 0.02)	-0.03 (-0.07, 0.02)	0.0237
Vitamin B-12	0.68 (0.65, 0.71)	-0.10 (-0.14, -0.06)*	-0.08 (-0.13, -0.04)*	-0.14 (-0.18, -0.09)*	-0.12 (-0.17, -0.08)*	<0.0001
Vitamin C	0.44 (0.41, 0.48)	-0.01 (-0.06, 0.04)	-0.01 (-0.06, 0.04)	-0.01 (-0.06, 0.04)	-0.02 (-0.07, 0.03)	0.7811
Vitamin D	0.04 (0.02, 0.05)	0.00 (-0.02, 0.01)	+0.01 (-0.01, 0.03)	-0.01 (-0.02, 0.01)	+0.30 (0.28, 0.32)*	<0.0001
Vitamin E	0.82 (0.80, 0.84)	+0.04 (0.01, 0.06)*	+0.02 (-0.01, 0.04)	+0.04 (0.01, 0.06)*	+0.01 (-0.02, 0.03)	<0.0001
Iodine	0.75 (0.73, 0.78)	-0.06 (-0.10, -0.03)*	-0.06 (-0.10, -0.02)*	-0.11 (-0.14, -0.07)*	-0.09 (-0.13, -0.05)*	<0.0001
Magnesium	0.86 (0.85, 0.88)	0.00 (-0.02, 0.03)	0.00 (-0.02, 0.03)	0.00 (-0.02, 0.03)	0.00 (-0.02, 0.03)	0.9761
Phosphorus	0.97 (0.96, 0.97)	0.00 (0.00, 0.01)	0.00 (-0.01, 0.01)	+0.01 (0.00, 0.02)	-0.01 (-0.02, 0.00)	0.0024
Potassium	0.65 (0.62, 0.68)	-0.05 (-0.10, -0.01)*	-0.05 (-0.09, 0.00)*	-0.06 (-0.1, -0.01)*	-0.05 (-0.10, -0.01)*	<0.0001
Selenium	0.94 (0.93, 0.95)	+0.01 (-0.01, 0.03)	+0.01 (-0.01, 0.03)	0.00 (-0.02, 0.02)	+0.01 (-0.01, 0.03)	0.1464
Zinc	0.32 (0.29, 0.35)	-0.02 (-0.06, 0.02)	-0.02 (-0.06, 0.02)	-0.02 (-0.06, 0.02)	-0.03 (-0.08, 0.01)	0.2471
Copper	0.85 (0.84, 0.87)	+0.03 (0.01, 0.05)*	+0.03 (0.01, 0.05)*	+0.02 (0.00, 0.04)*	+0.01 (0.00, 0.03)	<0.0001
Manganese	0.86 (0.84, 0.87)	+0.04 (0.01, 0.06)*	+0.02 (0.00, 0.05)*	+0.05 (0.02, 0.07)*	+0.02 (0.00, 0.05)*	<0.0001
Calcium	0.70 (0.67, 0.73)	-0.16 (-0.21, -0.12)*	-0.03 (-0.08, 0.01)	-0.18 (-0.23, -0.14)*	-0.04 (-0.08, 0.01)	<0.0001
Iron	0.58 (0.56, 0.61)	+0.04 (0.00, 0.07)	+0.03 (0.00, 0.07)	+0.04 (0.01, 0.08)*	+0.03 (-0.01, 0.07)	0.0096
Moderation Sub-score (MS) (0-100)	73.28 (72.21, 74.34)	-0.42 (-2.06, 1.22)	-0.31 (-1.95, 1.33)	-0.49 (-2.13, 1.15)	-0.64 (-2.28, 1.00)	0.8518
Probabilities of adequacy for MS components (0-1)						
Carbohydrates	0.95 (0.94, 0.96)	0.00 (-0.01, 0.02)	0.00 (-0.01, 0.02)	-0.02 (-0.04, -0.01)*	-0.02 (-0.04, -0.01)*	<0.0001
Protein	0.95 (0.94, 0.96)	+0.01 (-0.01, 0.02)	0.00 (-0.01, 0.02)	+0.01 (-0.01, 0.02)	+0.01 (-0.01, 0.02)	0.4662
Total fat	0.92 (0.91, 0.94)	-0.02 (-0.04, 0.00)	-0.01 (-0.03, 0.01)	+0.01 (-0.01, 0.03)	+0.01 (-0.01, 0.03)	<0.0001
SFA	0.30 (0.28, 0.33)	+0.02 (-0.02, 0.06)	+0.04 (-0.01, 0.08)	+0.07 (0.03, 0.11)*	+0.07 (0.03, 0.11)*	<0.0001
Sodium	0.58 (0.55, 0.61)	0.00 (-0.04, 0.05)	0.00 (-0.05, 0.05)	+0.01 (-0.03, 0.06)	+0.02 (-0.03, 0.07)	0.6399
Sugars without lactose	0.71 (0.68, 0.74)	-0.03 (-0.08, 0.01)	-0.04 (-0.09, 0.00)	-0.10 (-0.15, -0.06)*	-0.13 (-0.17, -0.08)*	<0.0001

[1] Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only milk consumers were selected (n=837). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated fatty acids.
[2] Values are means with a 95% confidence interval.
[3] Values are differences in means between the simulated diet and the initial diet with a 95% confidence interval of the difference. * Mean of the simulated diet significantly different from the mean of the initial diet.
[4] P for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplemental Table 7. PANDiet, AS, MS and probabilities of adequacies of the initial diet and differences observed in different scenarios of substitutions of milk items with milk substitutes according to the substitute's main constituting ingredient in French adults (n=837)[1].

MILK SUBSTITUTION MODEL					
	Initial diet[1]	Simulation of substitution of milk items with milk substitute according to the substitute's main constituting ingredient[2]			P[3] (model)
		Soy-based substitutes	Cereal-based substitutes	Nut-based substitutes	
PANDiet score (0-100)	69.04 (68.52, 69.56)	+0.29 (-0.49, 1.06)	-1.08 (-1.85, -0.31)*	-1.19 (-1.96, -0.42)*	<0.0001
Adequacy Sub-score (AS) (0-100)	64.81 (63.63, 65.98)	+0.82 (-0.94, 2.57)	-1.60 (-3.36, 0.15)	-1.81 (-3.57, -0.05)*	0.0001
Probabilities of adequacy for AS components (0-1)					
Protein	0.85 (0.83, 0.87)	0.00 (-0.04, 0.03)	-0.04 (-0.07, -0.01)*	-0.04 (-0.07, -0.01)*	<0.0001
LA	0.43 (0.41, 0.46)	+0.21 (0.17, 0.25)*	+0.16 (0.12, 0.20)*	+0.11 (0.07, 0.15)*	<0.0001
ALA	0.11 (0.09, 0.13)	+0.06 (0.03, 0.08)*	+0.05 (0.02, 0.07)*	0.00 (-0.03, 0.03)	<0.0001
DHA	0.22 (0.19, 0.25)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0.9794
EPA+DHA	0.19 (0.17, 0.22)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0.9974
Fiber	0.32 (0.30, 0.35)	+0.05 (0.01, 0.09)*	+0.02 (-0.02, 0.06)	+0.04 (0.00, 0.08)	0.0123
Vitamin A	0.49 (0.46, 0.52)	+0.03 (-0.01, 0.07)	-0.04 (-0.08, 0.01)	-0.04 (-0.08, 0.01)	<0.0001
Thiamine	0.98 (0.97, 0.98)	0.00 (-0.01, 0.00)	-0.01 (-0.02, 0.00)	-0.01 (-0.02, -0.01)*	0.0001
Riboflavin	0.80 (0.77, 0.83)	-0.06 (-0.10, -0.02)*	-0.13 (-0.17, -0.10)*	-0.12 (-0.16, -0.08)*	<0.0001
Niacin	0.998 (0.997, 0.999)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.6583
Pantothenic acid	0.89 (0.87, 0.90)	-0.04 (-0.06, -0.02)*	-0.04 (-0.06, -0.02)*	-0.05 (-0.07, -0.03)*	<0.0001
Vitamin B-6	0.66 (0.63, 0.69)	0.00 (-0.04, 0.04)	-0.01 (-0.05, 0.03)	-0.02 (-0.06, 0.02)	0.4509
Folate	0.65 (0.63, 0.68)	+0.03 (-0.01, 0.07)	-0.03 (-0.07, 0.01)	-0.02 (-0.07, 0.02)	0.0003
Vitamin B-12	0.68 (0.65, 0.71)	-0.07 (-0.11, -0.03)*	-0.13 (-0.18, -0.09)*	-0.13 (-0.17, -0.09)*	<0.0001
Vitamin C	0.44 (0.41, 0.48)	-0.01 (-0.06, 0.03)	-0.02 (-0.06, 0.03)	-0.01 (-0.05, 0.04)	0.8092
Vitamin D	0.04 (0.03, 0.04)	+0.10 (0.09, 0.12)*	-0.01 (-0.02, 0.01)	0.00 (-0.02, 0.01)	<0.0001
Vitamin E	0.82 (0.80, 0.84)	0.00 (-0.02, 0.02)	+0.05 (0.03, 0.08)*	+0.04 (0.02, 0.07)*	<0.0001
Iodine	0.75 (0.73, 0.77)	-0.08 (-0.12, -0.04)*	-0.12 (-0.16, -0.08)*	-0.06 (-0.09, -0.02)*	<0.0001
Magnesium	0.86 (0.85, 0.88)	+0.01 (-0.01, 0.03)	+0.01 (-0.01, 0.03)	0.00 (-0.03, 0.02)	0.1480
Phosphorus	0.97 (0.96, 0.97)	0.00 (-0.01, 0.01)	+0.01 (0.00, 0.01)	0.00 (-0.01, 0.01)	0.2189
Potassium	0.65 (0.62, 0.68)	-0.02 (-0.07, 0.02)	-0.07 (-0.11, -0.03)*	-0.07 (-0.11, -0.03)*	<0.0001
Selenium	0.94 (0.93, 0.95)	+0.01 (0.00, 0.03)	-0.01 (-0.03, 0.00)	+0.01 (0.00, 0.03)	0.0001
Zinc	0.32 (0.29, 0.35)	-0.01 (-0.05, 0.02)	0.00 (-0.04, 0.04)	-0.04 (-0.08, 0.00)	0.0328
Copper	0.85 (0.84, 0.87)	+0.04 (0.02, 0.06)*	+0.02 (0.00, 0.04)*	+0.02 (0.00, 0.04)*	<0.0001
Manganese	0.86 (0.84, 0.87)	+0.03 (0.01, 0.05)*	+0.06 (0.03, 0.08)*	+0.03 (0.01, 0.05)*	<0.0001
Calcium	0.70 (0.67, 0.73)	-0.09 (-0.13, -0.04)*	-0.18 (-0.22, -0.14)*	-0.14 (-0.18, -0.10)*	<0.0001
Iron	0.58 (0.56, 0.61)	+0.04 (0.01, 0.08)*	+0.06 (0.02, 0.09)*	+0.02 (-0.01, 0.06)	0.0001
Moderation Sub-score (MS) (0-100)	73.28 (72.25, 74.30)	-0.24 (-1.78, 1.29)	-0.56 (-2.09, 0.98)	-0.57 (-2.10, 0.97)	0.7231
Probabilities of adequacy for MS components (0-1)					
Carbohydrates	0.95 (0.94, 0.96)	0.00 (-0.01, 0.02)	-0.02 (-0.03, 0.00)*	-0.01 (-0.03, 0.00)	0.0004
Protein	0.95 (0.94, 0.96)	0.00 (-0.01, 0.02)	+0.01 (-0.01, 0.02)	+0.01 (-0.01, 0.02)	0.1906
Total fat	0.92 (0.91, 0.94)	0.00 (-0.02, 0.02)	0.00 (-0.01, 0.02)	-0.01 (-0.03, 0.01)	0.1757
SFA	0.30 (0.28, 0.33)	+0.05 (0.01, 0.08)*	+0.05 (0.01, 0.09)*	+0.03 (-0.01, 0.07)	0.0011
Sodium	0.58 (0.55, 0.61)	+0.01 (-0.04, 0.05)	+0.01 (-0.04, 0.05)	+0.01 (-0.03, 0.05)	0.9428
Sugars without lactose	0.71 (0.68, 0.74)	-0.06 (-0.1, -0.02)*	-0.09 (-0.13, -0.05)*	-0.06 (-0.10, -0.02)*	<0.0001

[1] Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only milk consumers were selected (n=837). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated fatty acids.
[2] Values are means with a 95% confidence interval.
[3] Values are differences of means between the simulated diet and the initial diet with a 95% confidence interval of the difference. * Mean of the simulated diet significantly different from the mean of the initial diet.
[4] P for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplemental Table 8. PANDiet, AS, MS and probabilities of adequacies of the initial diet and differences observed in different scenarios of substitutions of dairy dessert items with dairy dessert substitutes according to the substitute's category in French adults (n=1666)[1].

	DAIRY DESSERT SUBSTITUTION MODEL						
		Simulation of substitution of dairy dessert items with dairy dessert substitute according to the substitute's category[3]					
	Initial diet[2]	Plain plant-based desserts	Plain plant-based desserts, calcium fortified	Sweet plant-based desserts	Sweet plant-based desserts, calcium fortified	Plant-based mousses	P[4] (model)
PANDiet score (0-100)	68.48 (68.09, 68.88)	+0.93 (0.30, 1.55)*	+1.35 (0.73, 1.98)*	+0.20 (-0.43, 0.82)	+0.27 (-0.36, 0.89)	-2.85 (-3.48, -2.23)*	<0.0001
Adequacy Sub-score (AS) (0-100)	64.26 (63.39, 65.13)	+0.91 (-0.45, 2.27)	+1.77 (0.41, 3.14)*	+0.05 (-1.31, 1.41)	-0.05 (-1.41, 1.31)	-2.46 (-3.83, -1.10)*	<0.0001
Probabilities of adequacy for AS components (0-1)							
Protein	0.85 (0.83, 0.87)	+0.01 (-0.01, 0.04)	+0.01 (-0.01, 0.04)	-0.02 (-0.04, 0.01)	-0.01 (-0.04, 0.01)	-0.07 (-0.10, -0.05)*	<0.0001
LA	0.43 (0.41, 0.45)	+0.22 (0.19, 0.25)*	+0.22 (0.19, 0.25)*	+0.14 (0.11, 0.17)*	+0.13 (0.11, 0.16)*	+0.22 (0.19, 0.25)*	<0.0001
ALA	0.11 (0.10, 0.13)	+0.06 (0.04, 0.09)*	+0.08 (0.06, 0.10)*	+0.02 (0.00, 0.04)	+0.03 (0.01, 0.05)*	-0.03 (-0.05, 0.00)*	<0.0001
DHA	0.23 (0.21, 0.25)	+0.01 (-0.03, 0.04)	+0.01 (-0.02, 0.04)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	-0.02 (-0.05, 0.01)	0.0946
EPA+DHA	0.20 (0.18, 0.22)	+0.01 (-0.03, 0.04)	+0.01 (-0.03, 0.04)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	-0.02 (-0.05, 0.01)	0.1279
Fiber	0.35 (0.33, 0.37)	+0.04 (0.00, 0.07)*	+0.07 (0.04, 0.11)*	+0.04 (0.01, 0.07)*	+0.03 (-0.01, 0.06)	+0.09 (0.06, 0.12)*	<0.0001
Vitamin A	0.50 (0.48, 0.53)	-0.02 (-0.05, 0.02)	-0.01 (-0.05, 0.02)	+0.01 (-0.02, 0.05)	-0.01 (-0.04, 0.03)	-0.09 (-0.12, -0.05)*	<0.0001
Thiamine	0.97 (0.97, 0.98)	0.00 (-0.01, 0.00)	0.00 (-0.01, 0.00)	0.00 (-0.01, 0.00)	-0.01 (-0.01, 0.00)	-0.02 (-0.03, -0.01)*	<0.0001
Riboflavin	0.76 (0.74, 0.78)	-0.12 (-0.16, -0.09)*	-0.12 (-0.15, -0.09)*	-0.05 (-0.08, -0.02)*	-0.10 (-0.13, -0.07)*	-0.16 (-0.19, -0.13)*	<0.0001
Niacin	0.998 (0.997, 0.998)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	0.00 (0.00, 0.00)	-0.001 (-0.002, 0.00)*	<0.0001
Pantothenic acid	0.87 (0.86, 0.88)	-0.03 (-0.04, -0.01)*	-0.03 (-0.05, -0.01)*	-0.04 (-0.05, -0.02)*	-0.04 (-0.06, -0.02)*	-0.08 (-0.10, -0.07)*	<0.0001
Vitamin B-6	0.66 (0.64, 0.68)	+0.01 (-0.03, 0.04)	+0.02 (-0.02, 0.05)	-0.01 (-0.04, 0.02)	-0.01 (-0.04, 0.03)	-0.13 (-0.17, -0.10)*	<0.0001
Folate	0.66 (0.64, 0.68)	+0.03 (0.00, 0.07)*	+0.03 (0.00, 0.06)	-0.03 (-0.06, 0.01)	-0.01 (-0.05, 0.02)	-0.12 (-0.15, -0.09)*	<0.0001
Vitamin B-12	0.62 (0.60, 0.64)	-0.04 (-0.07, 0.00)*	-0.01 (-0.05, 0.02)	0.00 (-0.04, 0.03)	-0.03 (-0.06, 0.01)	-0.10 (-0.14, -0.07)*	<0.0001
Vitamin C	0.45 (0.43, 0.47)	+0.01 (-0.02, 0.05)	+0.02 (-0.02, 0.05)	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	-0.06 (-0.10, -0.03)*	<0.0001
Vitamin D	0.04 (0.03, 0.04)	-0.01 (-0.02, 0.00)	-0.01 (-0.01, 0.00)	-0.01 (-0.02, 0.00)*	-0.01 (-0.02, 0.00)	-0.01 (-0.02, 0.00)	0.0361
Vitamin E	0.82 (0.81, 0.83)	+0.06 (0.04, 0.07)*	+0.05 (0.04, 0.07)*	+0.02 (0.00, 0.04)*	+0.03 (0.01, 0.05)*	+0.04 (0.03, 0.06)*	<0.0001
Iodine	0.71 (0.69, 0.73)	-0.02 (-0.05, 0.01)	0.00 (-0.03, 0.03)	-0.02 (-0.05, 0.01)	-0.03 (-0.06, 0.00)*	-0.14 (-0.17, -0.11)*	<0.0001
Magnesium	0.87 (0.86, 0.88)	+0.02 (0.00, 0.03)	+0.02 (0.00, 0.03)*	+0.01 (0.00, 0.03)	+0.01 (-0.01, 0.02)	+0.03 (0.01, 0.04)*	<0.0001
Phosphorus	0.97 (0.97, 0.98)	0.00 (0.00, 0.01)	0.00 (-0.01, 0.00)	0.00 (0.00, 0.01)	0.00 (-0.01, 0.00)	0.00 (0.00, 0.01)	0.0036
Potassium	0.63 (0.61, 0.65)	-0.01 (-0.04, 0.02)	0.00 (-0.03, 0.03)	-0.01 (-0.05, 0.02)	-0.02 (-0.06, 0.01)	-0.06 (-0.09, -0.02)*	<0.0001
Selenium	0.94 (0.93, 0.95)	+0.01 (0.00, 0.02)	+0.01 (0.00, 0.03)*	+0.01 (0.00, 0.02)	+0.01 (0.00, 0.02)	-0.01 (-0.02, 0.00)	<0.0001
Zinc	0.31 (0.29, 0.33)	0.00 (-0.03, 0.03)	0.00 (-0.03, 0.03)	-0.01 (-0.04, 0.02)	-0.02 (-0.05, 0.01)	0.00 (-0.03, 0.03)	0.3129
Copper	0.87 (0.86, 0.87)	+0.03 (0.02, 0.04)*	+0.03 (0.02, 0.04)*	+0.03 (0.01, 0.04)*	+0.02 (0.00, 0.03)*	+0.05 (0.04, 0.06)*	<0.0001
Manganese	0.88 (0.87, 0.89)	+0.04 (0.02, 0.05)*	+0.04 (0.02, 0.05)*	+0.03 (0.01, 0.04)*	+0.03 (0.02, 0.05)*	+0.03 (0.01, 0.04)*	<0.0001
Calcium	0.63 (0.61, 0.66)	-0.11 (-0.14, -0.07)*	+0.01 (-0.02, 0.05)	-0.13 (-0.16, -0.09)*	-0.02 (-0.06, 0.01)	-0.18 (-0.21, -0.14)*	<0.0001
Iron	0.59 (0.58, 0.61)	+0.04 (0.01, 0.06)*	+0.03 (0.00, 0.05)*	+0.03 (0.01, 0.06)*	+0.02 (0.00, 0.05)	+0.18 (0.15, 0.21)*	<0.0001
Moderation Sub-score (MS) (0-100)	72.71 (71.94, 73.48)	+0.94 (-0.26, 2.15)	+0.93 (-0.28, 2.14)	+0.34 (-0.87, 1.55)	+0.58 (-0.63, 1.79)	-3.24 (-4.45, -2.03)*	<0.0001
Probabilities of adequacy for MS components (0-1)							
Carbohydrates	0.95 (0.95, 0.96)	+0.01 (0.00, 0.02)	+0.01 (0.00, 0.02)	-0.01 (-0.02, 0.00)	-0.02 (-0.03, 0.00)*	+0.02 (0.01, 0.03)*	<0.0001
Protein	0.96 (0.95, 0.96)	-0.01 (-0.02, 0.01)	-0.01 (-0.02, 0.01)	0.00 (-0.01, 0.02)	0.00 (-0.01, 0.01)	+0.01 (0.00, 0.03)*	<0.0001
Total fat	0.91 (0.90, 0.93)	-0.01 (-0.03, 0.01)	-0.01 (-0.03, 0.01)	0.00 (-0.01, 0.02)	+0.01 (-0.01, 0.03)	-0.09 (-0.11, -0.07)*	<0.0001
SFA	0.30 (0.28, 0.31)	+0.06 (0.03, 0.09)*	+0.06 (0.03, 0.09)*	+0.06 (0.03, 0.09)*	+0.09 (0.06, 0.12)*	-0.13 (-0.16, -0.10)*	<0.0001
Sodium	0.57 (0.55, 0.59)	-0.02 (-0.06, 0.01)	-0.02 (-0.06, 0.01)	+0.01 (-0.03, 0.04)	0.00 (-0.03, 0.03)	+0.08 (0.05, 0.12)*	<0.0001
Sugars without lactose	0.70 (0.68, 0.72)	+0.03 (0.00, 0.06)	+0.03 (0.00, 0.07)*	-0.04 (-0.08, -0.01)*	-0.05 (-0.08, -0.02)*	-0.10 (-0.14, -0.07)*	<0.0001

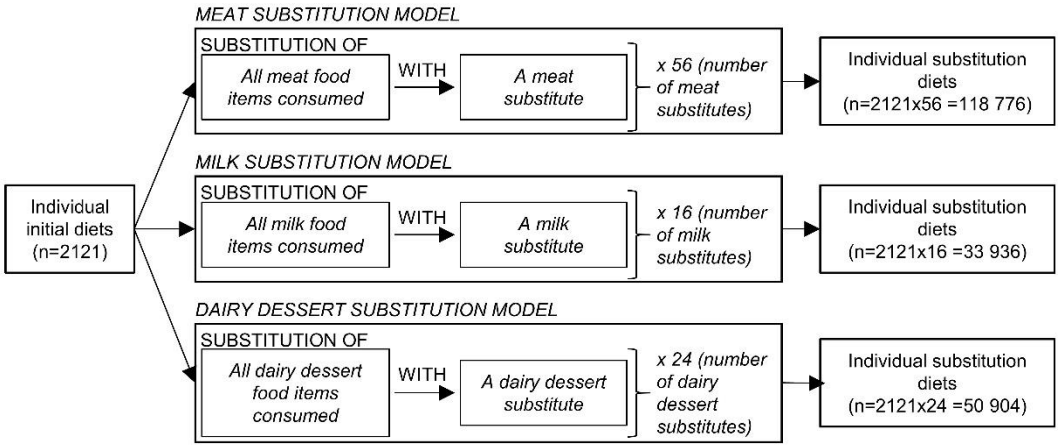
[1] Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only dairy dessert consumers were selected (n=1666). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated fatty acids.
[2] Values are means with a 95% confidence interval.
[3] Values are differences in means between the simulated diet and the initial diet with a 95% confidence interval of the difference. * Mean of the simulated diet significantly different from the mean of the initial diet.
[4] P for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplemental Table 9. PANDiet, AS, MS and probabilities of adequacies of the initial diet and differences observed in different scenarios of substitutions of dairy dessert items with dairy dessert substitutes according to the substitute's main constituting ingredient in French adults (n=1666)[1].

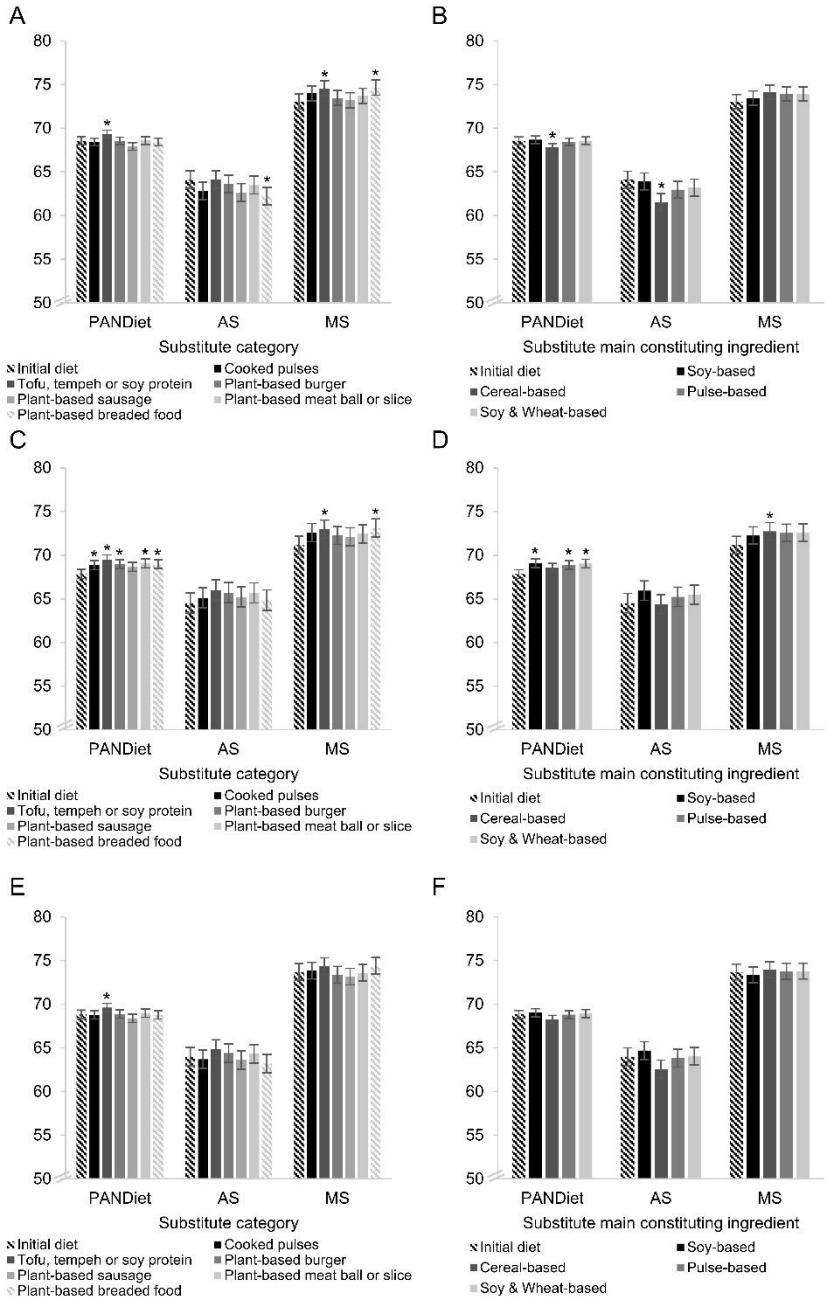
DAIRY DESSERT SUBSTITUTION MODEL				
	Initial diet[2]	Simulation of substitution of dairy dessert items with dairy dessert substitute according to the substitute's main constituting ingredient[3]		P[4] (model)
		Soy-based substitutes	Non soy-based substitutes	
PANDiet score (0-100)	68.48 (68.13, 68.84)	+0.60 (0.10, 1.10)*	-1.31 (-1.80, -0.81)*	<0.0001
Adequacy Sub-score (AS) (0-100)	64.26 (63.47, 65.05)	+0.45 (-0.67, 1.56)	-1.25 (-2.36, -0.13)*	0.0008
Probabilities of adequacy for AS components (0-1)				
Protein	0.85 (0.84, 0.87)	0.00 (-0.03, 0.02)	-0.05 (-0.07, -0.03)*	<0.0001
LA	0.43 (0.41, 0.45)	+0.16 (0.14, 0.19)*	+0.14 (0.12, 0.17)*	<0.0001
ALA	0.11 (0.10, 0.13)	+0.04 (0.02, 0.06)*	-0.01 (-0.03, 0.01)	<0.0001
DHA	0.23 (0.21, 0.25)	0.00 (-0.02, 0.03)	-0.01 (-0.03, 0.02)	0.6001
EPA+DHA	0.20 (0.18, 0.22)	0.00 (-0.02, 0.03)	-0.01 (-0.03, 0.02)	0.5777
Fiber	0.35 (0.33, 0.37)	+0.04 (0.01, 0.06)*	+0.07 (0.04, 0.09)*	<0.0001
Vitamin A	0.50 (0.48, 0.52)	+0.01 (-0.02, 0.04)	-0.06 (-0.09, -0.03)*	<0.0001
Thiamine	0.97 (0.97, 0.98)	0.00 (-0.01, 0.00)	-0.01 (-0.02, -0.01)*	<0.0001
Riboflavin	0.76 (0.74, 0.78)	-0.07 (-0.10, -0.05)*	-0.13 (-0.15, -0.10)*	<0.0001
Niacin	0.998 (0.997, 0.998)	0.00 (0.00, 0.00)	-0.001 (-0.002, 0.00)*	0.0457
Pantothenic acid	0.87 (0.86, 0.88)	-0.03 (-0.05, -0.02)*	-0.06 (-0.07, -0.05)*	<0.0001
Vitamin B-6	0.66 (0.64, 0.68)	0.00 (-0.02, 0.03)	-0.07 (-0.10, -0.04)*	<0.0001
Folate	0.66 (0.64, 0.68)	0.00 (-0.03, 0.03)	-0.08 (-0.11, -0.05)*	<0.0001
Vitamin B-12	0.62 (0.60, 0.64)	0.00 (-0.03, 0.02)	-0.08 (-0.11, -0.05)*	<0.0001
Vitamin C	0.45 (0.43, 0.47)	+0.01 (-0.03, 0.04)	-0.03 (-0.06, 0.00)	0.0232
Vitamin D	0.04 (0.03, 0.04)	-0.01 (-0.02, 0.00)*	-0.01 (-0.02, 0.00)*	0.0039
Vitamin E	0.82 (0.81, 0.83)	+0.03 (0.01, 0.04)*	+0.04 (0.03, 0.06)*	<0.0001
Iodine	0.71 (0.69, 0.73)	-0.04 (-0.06, -0.02)*	0.00 (-0.02, 0.02)	<0.0001
Magnesium	0.87 (0.86, 0.87)	+0.01 (0.00, 0.02)	+0.03 (0.01, 0.04)*	<0.0001
Phosphorus	0.97 (0.97, 0.98)	0.00 (0.00, 0.01)	0.00 (0.00, 0.01)	0.3282
Potassium	0.63 (0.61, 0.65)	-0.02 (-0.04, 0.01)	-0.03 (-0.05, 0.00)	0.0605
Selenium	0.94 (0.93, 0.95)	+0.01 (0.00, 0.02)	0.00 (-0.01, 0.01)	0.0523
Zinc	0.31 (0.29, 0.33)	-0.01 (-0.04, 0.01)	0.00 (-0.03, 0.02)	0.3888
Copper	0.87 (0.86, 0.87)	+0.02 (0.01, 0.03)*	+0.04 (0.02, 0.05)*	<0.0001
Manganese	0.88 (0.87, 0.89)	+0.03 (0.02, 0.04)*	+0.03 (0.02, 0.05)*	<0.0001
Calcium	0.63 (0.61, 0.65)	-0.06 (-0.09, -0.04)*	-0.14 (-0.17, -0.11)*	<0.0001
Iron	0.59 (0.58, 0.61)	+0.03 (0.00, 0.05)*	+0.09 (0.07, 0.11)*	<0.0001
Moderation Sub-score (MS) (0-100)	72.71 (72.02, 73.40)	+0.75 (-0.23, 1.72)	-1.36 (-2.34, -0.39)*	<0.0001
Probabilities of adequacy for MS components (0-1)				
Carbohydrates	0.95 (0.95, 0.96)	-0.01 (-0.02, 0.00)*	0.00 (0.00, 0.01)	0.0007
Protein	0.96 (0.95, 0.96)	0.00 (-0.01, 0.01)	+0.01 (0.00, 0.02)	0.0246
Total fat	0.91 (0.90, 0.92)	+0.01 (-0.01, 0.02)	-0.04 (-0.05, -0.02)*	<0.0001
SFA	0.30 (0.28, 0.31)	+0.09 (0.06, 0.11)*	-0.05 (-0.07, -0.02)*	<0.0001
Sodium	0.57 (0.55, 0.59)	-0.01 (-0.03, 0.02)	+0.04 (0.01, 0.07)*	<0.0001
Sugars without lactose	0.70 (0.68, 0.72)	-0.03 (-0.06, -0.01)*	-0.05 (-0.08, -0.03)*	<0.0001

[1] Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only dairy dessert consumers were selected (n=1666). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated fatty acids.
[2] Values are means with a 95% confidence interval.
[3] Values are differences in means between the simulated diet and the initial diet with a 95% confidence interval of the difference. * Mean of the simulated diet significantly different from the mean of the initial diet.
[4] P for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplementary data.



Supplemental Figure 1. Diagram describing the method for the substitution of animal products with plant-based substitutes.



Supplemental Figure 2. PANDiet scores, Adequacy Sub-scores (AS) and Moderation Sub-scores (MS) for the initial diet and substitution diets according to the substitute category or to the main constituting ingredient of the substitute in the three sub-models of meat substitution. (A, B) “Beef substitution model” (n=1371) simulated diets gathered by the substitute categories (A) or by the main constituting ingredient of substitutes (B); (C, D) “Pork substitution model” (n=933) simulated diets gathered by the substitute categories (C) or by the main constituting ingredient of substitutes (D); (E, F) “Poultry substitution model” (n=1144) simulated diets gathered by the substitute categories (E) or by the main constituting ingredient of substitutes (F); Values are means with 95% confidence intervals of the mean. * Significantly different from the initial diet, assessed by ANOVA and post-hoc tests with Bonferroni correction, at P<0.05. AS, Adequacy sub-score; MS, Moderation sub-score; PANDiet, Probability of Adequate Nutrient Intake.

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