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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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4 Figures, 2 Tables

2 Supplementary Data (STROBE-NUT checklist, 1 supplemental method, 9 Supplemental Tables, 2 Supplemental Figures)

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.

1 **Abstract**

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

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

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

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

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

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

29 **Introduction**

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

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

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

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

53 effects such as a lower risk of cardiovascular diseases (21,22), this is dependent on the types of
54 plant-based foods being consumed (23,24). Plant-based substitutes are often ultra-processed
55 (9,18) and the excessive consumption of ultra-processed foods has been associated with several
56 adverse health effects (25–27).

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

64 **Subjects and methods**

65 Population data

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

72 Dietary data

73 The foods and beverages consumed by individuals were obtained through three non-consecutive
74 24h-dietary recalls consisting of two weekdays and one weekend day spread over three weeks.
75 Dietary data were collected by a telephone interview assisted by dietary software. The participants
76 were not aware of the days of recall so they could not change their diet in anticipation of the call.
77 Validated photographs were used to estimate portion sizes (30). The nutrient contents of different
78 foods and beverages were extracted from the 2016 food composition database from the French
79 Information Centre on Food Quality (CIQUAL) (32).

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

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

90 Database on plant-based substitutes

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

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

109 *Identification of substitutable food items*

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

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

120 *Method of substitution*

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

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

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

138 For every model, all substitutable food items were replaced by the same plant-based substitute
139 and we implemented as many substitutions as we had plant-based substitutes available. For
140 example, in the “Meat substitution model”, the first substitution involved all meat items being
141 replaced by the “Falafel” substitute, while under the second substitution they were replaced by the
142 “Plant-based sausage with wheat or seitan” substitute, until all substitutes had been tested. Fifty-
143 six substitutes were available for the “Meat substitution model”, so we implemented 56 different
144 replacements. In the same way, 16 replacements were made under the “Milk substitution model”
145 and 24 under the “Dairy dessert substitution model”. All individual diets were then evaluated for
146 their nutritional quality. The simulation yielded a total of $2121 \times 96 = 203,616$ simulated diets.

147 *Evaluation of the nutritional quality of the diet*

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

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

164 Evaluation of the nutrient security of the diet

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

179 Statistical analysis

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

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

193 All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA.).

194 Significance was set at $P < 0.05$.

195 **Results**

196 *Substitution of meat food items with plant-based meat substitutes (“Meat substitution model”)*

197 When replacing meat food items with plant-based meat substitutes (n=1949 consumers), the
198 mean PANDiet score ranged from 67.1 to 70.4 (vs 68.3 for the initial diet) across the different
199 substitution diets (i.e. across the different plant-based substitutes used). In particular, the AS
200 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
201 ranged from 0.89 to 0.94 (vs 0.92). On average over all the substitutes used, diet quality and
202 nutrient security were therefore only marginally affected by the substitution. By contrast, the
203 percentage of plant protein increased (ranging from 45.2% to 61.5% vs 31.7% in the initial diet),
204 as did the percentage of energy intake from UPF (except with cooked pulses, tofu and tempeh)
205 which ranged from 27.2% to 39.5% (vs 28.6% in the initial diet) (**Table 2**).

206 More specifically regarding the substitutes used, the PANDiet score was increased after
207 substitutions using “Tofu, tempeh or soy protein” (+1.58 points) or “Soy-based” (+0.57 points)
208 substitutes and decreased with “Plant-based sausage” (-0.60 points) or “Cereal-based” (-0.72
209 points) substitutes (all $P_s < 0.0001$). In particular, the AS score remained stable or decreased (the
210 most important decrease concerning substitution with “Cereal-based” substitutes (-3.08 points,
211 $P < 0.0001$)) while the MS remained stable or increased (the greatest increase concerning “Plant-
212 based beaded food” substitutes (+2.51 points, $P < 0.0001$)) (**Figure 1**, Supplemental Tables 4 and
213 5).

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

219 probabilities of adequacy of the MS score (i) increased (i.e. less excessive intake) for saturated
220 fatty acids (SFA) and to a lesser extent for total fat and protein, and (ii) decreased (i.e. more
221 excessive intake) for sodium and to a lesser extent for carbohydrates (Supplemental Tables 4 and
222 5).

223 The SecDiet score decreased after substitution with “Plant-based breaded food” (-0.01 points,
224 $P=0.0011$) and “Cereal-based” (-0.02 points, $P<0.0001$) substitutes (**Figure 2**). Probabilities
225 decreases (i.e. an elevated risk of deficiency) were the most important for riboflavin (max. -0.05
226 points, $P<0.0001$), vitamin B-12 (max. -0.05 points, $P<0.0001$) and bioavailable iron (max. -0.03
227 points, $P<0.0001$), whereas probabilities increased (i.e. less risk of deficiency) for folate (max.
228 +0.04 points, $P<0.0001$) and calcium (max. +0.03 points, $P<0.0001$).

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

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

237 When replacing milk items with plant-based milk substitutes (n=837 consumers), the PANDiet
238 score across the different substitution diets ranged from 66.7 to 70.0 (vs 69.0 for the initial diet).
239 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
240 score mainly decreased (0.91-0.93 vs 0.93 for the initial diet). The percentage of plant protein in
241 the diet increased systematically (34.1% - 38.9% vs 31.4% in the initial diet) as the percentage of
242 energy intake from UPF (31.6% - 34.8% vs 29.6%) (Table 2).

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

253 The SecDiet score systematically decreased after substitution, and the most marked decreases
254 were obtained with “Nut-based” and “Sweet plant-based milk” substitutes (both -0.02 points,
255 $P_s<0.0001$) (**Figure 3**). The decreases in probabilities were the most marked for iodine (max. -
256 0.06 points, $P<0.0001$), riboflavin (max. -0.05 points, $P<0.0001$), calcium (max. -0.04 points,
257 $P<0.0001$) and vitamin A (max. -0.03 points, $P<0.0001$). The calcium probability did not decrease
258 with “Plain plant-based milk, calcium-fortified” and “Sweet plant-based milk, calcium-fortified”
259 substitutes.

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

262 When replacing dairy dessert items with plant-based dairy dessert substitutes (n=1666
263 consumers), the PANDiet scores across the different substitution diets ranged from 65.2 to 70.0
264 (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
265 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).
266 The percentage of plant protein in the diet (initially 32.1%) increased between 34.5% and 42.3%.

267 The percentage of energy intake from UPF (initially 29.3%) generally increased, to reach between
268 28.9% and 40.5% (Table 2).

269 More specifically, the PANDiet score increased with “Plain plant-based dessert, calcium-fortified”
270 (+1.35 points), “Plain plant-based dessert” (+0.93 points) and “Soy-based” (+0.60 points)
271 substitutes and decreased with “Plant-based mousse” (-2.85 points) and “Non-soy based” (-1.31
272 points) substitutes (all P s<0.0001). The AS increased with “Plain plant-based dessert, calcium-
273 fortified” substitutes (+1.77 points, P <0.0001) and both the AS and the MS decreased with “Plant-
274 based mousse” (-2.46 points for AS, P <0.0001, -3.24 points for MS, P <0.0001) and “Non soy-
275 based” (-1.25 points for AS, P =0.0008, -1.36 points for MS, P <0.0001) substitutes (Figure 1).

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

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

287 **Discussion**

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

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

298 Impacts of substitutions on nutrients that need to be limited

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

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

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

319 Impact of substitutions on nutrient adequacy and security

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

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

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

344 Impact of substitutions depending on the type of substitutes

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

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

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

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

376 Limitations of the study

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

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

397 Conclusion

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

406 Overall, the impact of plant-based substitutes on diet quality was small but varied: the nutritional
407 impact of some substitutes proved to be positive, such as those that include legumes, but others
408 proved to be negative, such as plant-based mousse as a replacement for dairy desserts. If seeking
409 to limit the share of ultra-processed foods in the diet, pulses, tofu or tempeh offer a good alternative
410 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)	Pulse-based (n=18) Cereal-based (n=6) Soy & Wheat-based (n=11) Soy-based (n=21)
	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)	
Milk substitutes (n=16)	Plant-based breaded foods (n=6)	Soy-based (n=6) Cereal-based (n=3) Nut-based (n=7)
	Plain plant-based milks (n=7)	
	Plain plant-based milks, calcium-fortified (n=3)	
	Sweet plant-based milks (n=4)	
Dairy dessert substitutes (n=24)	Sweet plant-based milks, calcium-fortified (n=2)	Soy-based (n=19) Non soy-based (n=5)
	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)	

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 population¹.

	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]

¹Data 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.

²Values are mean ± SD.

³Values 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

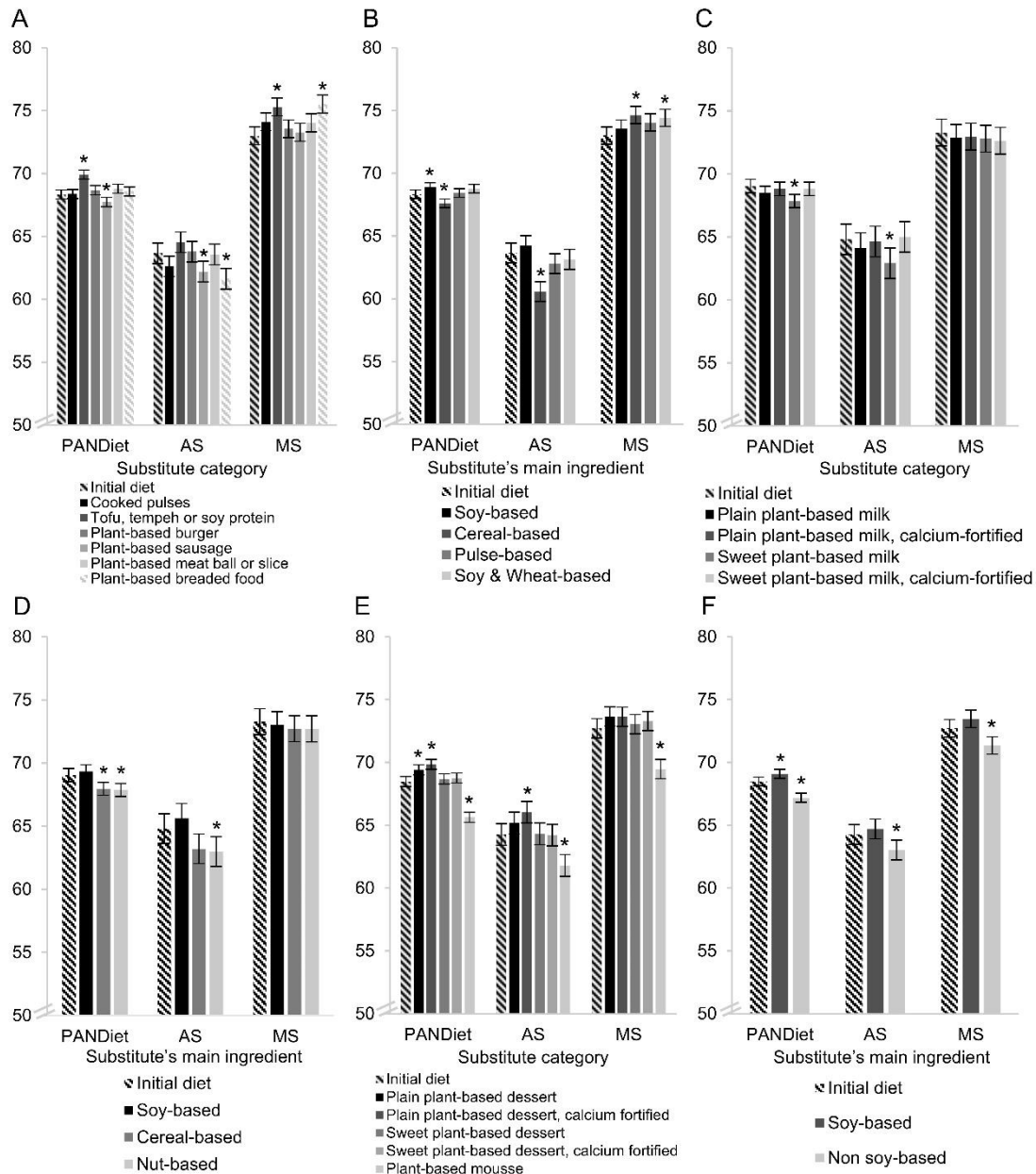


Figure 1. PANDiet score, Adequacy Sub-score (AS) and Moderation Sub-score (MS) for the initial diet and substitution diets according to the substitute category or to the main constituting ingredient of the substitute, for the three substitution models. (A, B) “Meat substitution model” (n=1949) simulated 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.

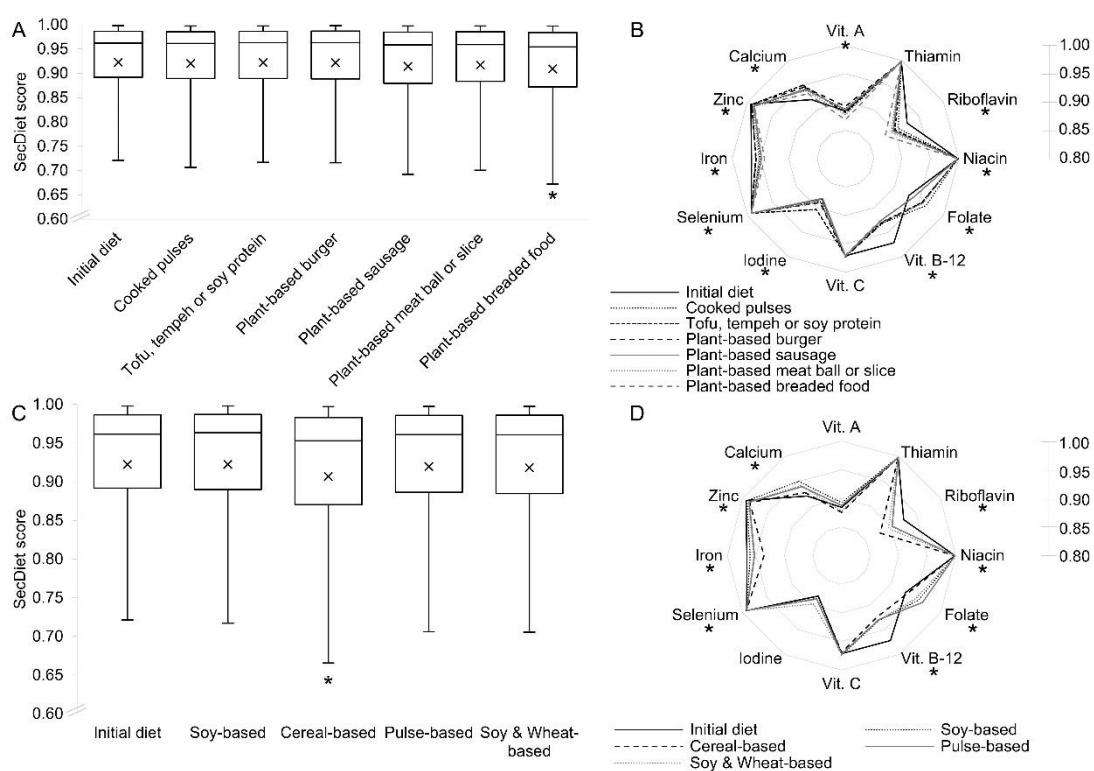


Figure 2. SecDiet score and probabilities for nutrients included in the SecDiet of avoiding overt nutrient deficiency in the initial diet and substitution diets of the “Meat substitution model” (n=1949). (A) SecDiet score and (B) its constituent probabilities in simulated diets gathered by substitute 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; * $P(\text{model}) < 0.05$ for the nutrient probability, assessed by Kruskal-Wallis tests.

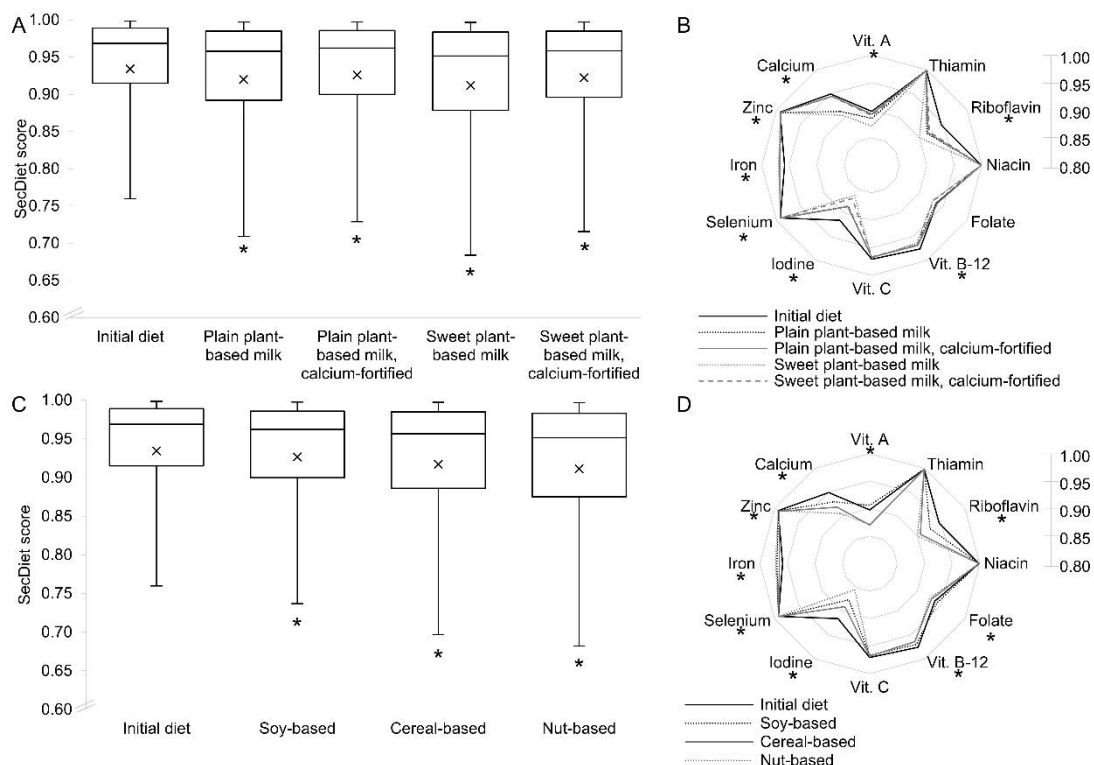


Figure 3. SecDiet score and probabilities for nutrients included in the SecDiet of avoiding overt nutrient deficiency in the initial diets and substitution diets of the “Milk substitution model” (n=837). (A) SecDiet score and (B) its constituent probabilities in simulated diets gathered by substitute 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; * $P(\text{model}) < 0.05$ for the nutrient probability, assessed by Kruskal-Wallis tests.

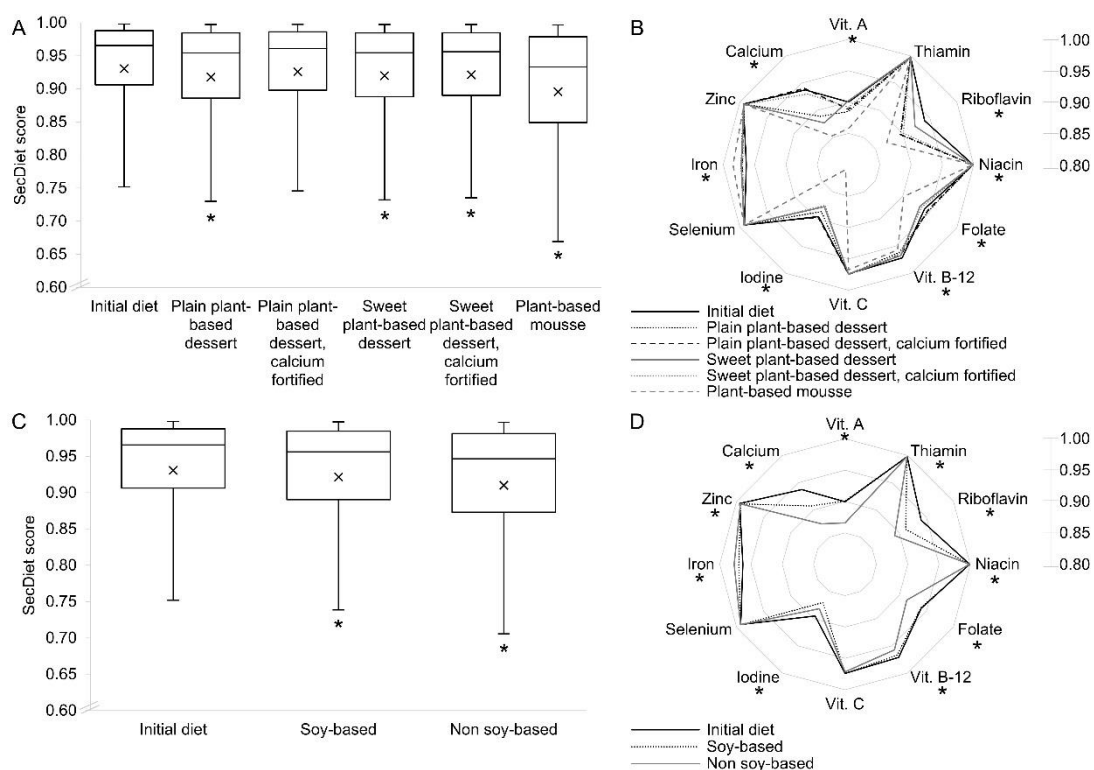


Figure 4. SecDiet score and probabilities for nutrients included in the SecDiet of avoiding overt nutrient deficiency in the initial diets and substitution diets of the “Dairy dessert substitution model” (n=1666). (A) SecDiet score and (B) its constituent probabilities in simulated diets gathered by 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; * $P(\text{model}) < 0.05$ for the nutrient probability, assessed by Kruskal-Wallis tests.

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) – Salomé et *al.* – Online Supplementary Material

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)

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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, plant-based	Yes	(4)
Dairy dessert substitute	Plant-based mousse	Non soy-based	Mousse, chocolate, plant-based, prepacked	Yes	(3)

1 Three 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			Moderation subscore		
Nutrient	Reference value (/day)(7)	Variability	Nutrient	Reference value (/day)(7)	Variability
Protein	0.66 or 0.8 g/kg bw	12.5%	Protein	2.2 g/kg bw	12.5%
LA	3.08% EIEA	15%	Total fat	44% EIEA	5%
ALA	0.769% EIEA	15%	SFA	12% EIEA	15%
DHA	0.192 g	15%	Carbohydrates	60.5% EIEA	5%
EPA + DHA	0.385 g	15%	Sugars	100 g	15%
Fiber	23 g	15%	Sodium	3200 mg	15%
Vitamin A	580 or 490 µg	15%	Tolerable Upper Intake Limits		
Thiamin	0.3 mg/1000 kcal	20%	Retinol	3000 µg	
Riboflavin	1.3 mg	10%	Niacin	900 mg	
Niacin	5.44 mg NE/1000kcal	10%	Vitamin B-6	25 mg	
Pantothenic acid	3.33 or 2.78 mg	40%	Folate	1170 µg	
Vitamin B-6	1.5 or 1.3 mg	10%	Vitamin D	100 µg	
Folate	250 µg	15%	Vitamin E	300 mg	
Vitamin B-12	3.33 µg	10%	Calcium	2500 mg	
Vitamin C	90 mg	10%	Copper	10 mg	
Vitamin D	10 µg	25%	Iodine	600 µg	
Vitamin E	5.26 or 4.74 mg	45%	Dissociable magnesium	250 mg	
Calcium	860 (<= 24 y.o.) or 750 mg (>24 y.o.)	15% or 13%	Selenium	300 µg	
Copper	0.86 or 0.68 mg	60%	Zinc	25 mg	
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%			

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

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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)	Xerophthalmia	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)).

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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							P ⁴ (model)
	Initial diet ²	Simulation of substitution of meat items with meat substitute according to the substitute's category ³						
		Cooked pulses	Tofu, tempeh or soy protein	Plant-based burgers	Plant-based sausages	Plant-based meat balls or slices	Plant-based breaded foods	
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)								
<i>Protein</i>	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
<i>LA</i>	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
<i>ALA</i>	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
<i>DHA</i>	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
<i>EPA+DHA</i>	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
<i>Fiber</i>	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
<i>Vitamin A</i>	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
<i>Thiamine</i>	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)*	-0.01 (-0.02, -0.01)*	<0.0001
<i>Riboflavin</i>	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
<i>Niacin</i>	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
<i>Pantothenic acid</i>	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
<i>Vitamin B-6</i>	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
<i>Folate</i>	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
<i>Vitamin B-12</i>	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
<i>Vitamin C</i>	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
<i>Vitamin D</i>	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
<i>Vitamin E</i>	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
<i>Iodine</i>	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
<i>Magnesium</i>	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
<i>Phosphorus</i>	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
<i>Potassium</i>	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
<i>Selenium</i>	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
<i>Zinc</i>	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
<i>Copper</i>	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
<i>Manganese</i>	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
<i>Calcium</i>	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
<i>Iron</i>	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)								
<i>Carbohydrates</i>	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
<i>Protein</i>	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
<i>Total fat</i>	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
<i>SFA</i>	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
<i>Sodium</i>	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
<i>Sugars without lactose</i>	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 were 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						
Simulation of substitution of meat items with meat substitute according to the substitute's main constituting ingredient ³						
	Initial diet ²	Soy-based substitutes	Cereal-based substitutes	Pulse-based substitutes	Soy & Wheat-based substitutes	P ⁴ (model)
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)						
<i>Protein</i>	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
<i>LA</i>	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
<i>ALA</i>	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
<i>DHA</i>	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
<i>EPA+DHA</i>	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
<i>Fiber</i>	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
<i>Vitamin A</i>	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
<i>Thiamine</i>	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
<i>Riboflavin</i>	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
<i>Niacin</i>	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
<i>Pantothenic acid</i>	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
<i>Vitamin B-6</i>	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
<i>Folate</i>	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
<i>Vitamin B-12</i>	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
<i>Vitamin C</i>	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
<i>Vitamin D</i>	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
<i>Vitamin E</i>	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
<i>Iodine</i>	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
<i>Magnesium</i>	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
<i>Phosphorus</i>	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
<i>Potassium</i>	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
<i>Selenium</i>	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
<i>Zinc</i>	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
<i>Copper</i>	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
<i>Manganese</i>	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
<i>Calcium</i>	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
<i>Iron</i>	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)						
<i>Carbohydrates</i>	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
<i>Protein</i>	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
<i>Total fat</i>	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
<i>SFA</i>	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
<i>Sodium</i>	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
<i>Sugars without lactose</i>	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 were 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 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					P ⁴ (model)
	Initial diet ²	Simulation of substitution of milk items with milk substitute according to the substitute's category ³				
		Plain plant-based milks	Plain plant-based milks, calcium-fortified	Sweet plant-based milks	Sweet plant-based milks, calcium-fortified	
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)						
<i>Protein</i>	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
<i>LA</i>	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
<i>ALA</i>	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
<i>DHA</i>	0.22 (0.19, 0.25)	0.00 (-0.04, 0.05)	0.00 (-0.05, 0.05)	0.00 (-0.04, 0.04)	0 (-0.04, 0.04)	0.9928
<i>EPA+DHA</i>	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
<i>Fiber</i>	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
<i>Vitamin A</i>	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
<i>Thiamine</i>	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
<i>Riboflavin</i>	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
<i>Niacin</i>	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
<i>Pantothenic acid</i>	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
<i>Vitamin B-6</i>	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
<i>Folate</i>	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
<i>Vitamin B-12</i>	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
<i>Vitamin C</i>	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
<i>Vitamin D</i>	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
<i>Vitamin E</i>	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
<i>Iodine</i>	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
<i>Magnesium</i>	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
<i>Phosphorus</i>	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
<i>Potassium</i>	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
<i>Selenium</i>	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
<i>Zinc</i>	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
<i>Copper</i>	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
<i>Manganese</i>	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
<i>Calcium</i>	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
<i>Iron</i>	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)						
<i>Carbohydrates</i>	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
<i>Protein</i>	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
<i>Total fat</i>	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
<i>SFA</i>	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
<i>Sodium</i>	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
<i>Sugars without lactose</i>	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.

Supplementary data.

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)					
<i>Protein</i>	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
<i>LA</i>	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
<i>ALA</i>	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
<i>DHA</i>	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
<i>EPA+DHA</i>	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
<i>Fiber</i>	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
<i>Vitamin A</i>	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
<i>Thiamine</i>	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
<i>Riboflavin</i>	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
<i>Niacin</i>	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
<i>Pantothenic acid</i>	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
<i>Vitamin B-6</i>	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
<i>Folate</i>	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
<i>Vitamin B-12</i>	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
<i>Vitamin C</i>	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
<i>Vitamin D</i>	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
<i>Vitamin E</i>	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
<i>Iodine</i>	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
<i>Magnesium</i>	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
<i>Phosphorus</i>	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
<i>Potassium</i>	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
<i>Selenium</i>	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
<i>Zinc</i>	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
<i>Copper</i>	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
<i>Manganese</i>	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
<i>Calcium</i>	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
<i>Iron</i>	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)					
<i>Carbohydrates</i>	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
<i>Protein</i>	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
<i>Total fat</i>	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
<i>SFA</i>	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
<i>Sodium</i>	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
<i>Sugars without lactose</i>	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.

Supplementary data.

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						
	Initial diet ²	Simulation of substitution of dairy dessert items with dairy dessert substitute according to the substitute's category ³					P ⁴ (model)
		Plain plant-based desserts	Plain plant-based desserts, calcium fortified	Sweet plant-based desserts	Sweet plant-based desserts, calcium fortified	Plant-based mousses	
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)							
<i>Protein</i>	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
<i>LA</i>	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
<i>ALA</i>	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
<i>DHA</i>	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
<i>EPA+DHA</i>	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
<i>Fiber</i>	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
<i>Vitamin A</i>	0.50 (0.48, 0.53)	-0.02 (-0.05, 0.02)	-0.01 (-0.05, 0.02)	+0.01 (-0.02, 0.05)	0.00 (0.00, 0.00)	-0.09 (-0.12, -0.05)*	<0.0001
<i>Thiamine</i>	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
<i>Riboflavin</i>	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
<i>Niacin</i>	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
<i>Pantothenic acid</i>	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
<i>Vitamin B-6</i>	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
<i>Folate</i>	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
<i>Vitamin B-12</i>	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
<i>Vitamin C</i>	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
<i>Vitamin D</i>	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
<i>Vitamin E</i>	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
<i>Iodine</i>	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
<i>Magnesium</i>	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
<i>Phosphorus</i>	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
<i>Potassium</i>	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
<i>Selenium</i>	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
<i>Zinc</i>	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
<i>Copper</i>	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
<i>Manganese</i>	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
<i>Calcium</i>	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
<i>Iron</i>	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)							
<i>Carbohydrates</i>	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
<i>Protein</i>	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
<i>Total fat</i>	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
<i>SFA</i>	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
<i>Sodium</i>	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
<i>Sugars without lactose</i>	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)	
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)				
<i>Protein</i>	0.85 (0.84, 0.87)	0.00 (-0.03, 0.02)	-0.05 (-0.07, -0.03)*	<0.0001
<i>LA</i>	0.43 (0.41, 0.45)	+0.16 (0.14, 0.19)*	+0.14 (0.12, 0.17)*	<0.0001
<i>ALA</i>	0.11 (0.10, 0.13)	+0.04 (0.02, 0.06)*	-0.01 (-0.03, 0.01)	<0.0001
<i>DHA</i>	0.23 (0.21, 0.25)	0.00 (-0.02, 0.03)	-0.01 (-0.03, 0.02)	0.6001
<i>EPA+DHA</i>	0.20 (0.18, 0.22)	0.00 (-0.02, 0.03)	-0.01 (-0.03, 0.02)	0.5777
<i>Fiber</i>	0.35 (0.33, 0.37)	+0.04 (0.01, 0.06)*	+0.07 (0.04, 0.09)*	<0.0001
<i>Vitamin A</i>	0.50 (0.48, 0.52)	+0.01 (-0.02, 0.04)	-0.06 (-0.09, -0.03)*	<0.0001
<i>Thiamine</i>	0.97 (0.97, 0.98)	0.00 (-0.01, 0.00)	-0.01 (-0.02, -0.01)*	<0.0001
<i>Riboflavin</i>	0.76 (0.74, 0.78)	-0.07 (-0.10, -0.05)*	-0.13 (-0.15, -0.10)*	<0.0001
<i>Niacin</i>	0.998 (0.997, 0.998)	0.00 (0.00, 0.00)	-0.001 (-0.002, 0.00)*	0.0457
<i>Pantothenic acid</i>	0.87 (0.86, 0.88)	-0.03 (-0.05, -0.02)*	-0.06 (-0.07, -0.05)*	<0.0001
<i>Vitamin B-6</i>	0.66 (0.64, 0.68)	0.00 (-0.02, 0.03)	-0.07 (-0.10, -0.04)*	<0.0001
<i>Folate</i>	0.66 (0.64, 0.68)	0.00 (-0.03, 0.03)	-0.08 (-0.11, -0.05)*	<0.0001
<i>Vitamin B-12</i>	0.62 (0.60, 0.64)	0.00 (-0.03, 0.02)	-0.08 (-0.11, -0.05)*	<0.0001
<i>Vitamin C</i>	0.45 (0.43, 0.47)	+0.01 (-0.03, 0.04)	-0.03 (-0.06, 0.00)	0.0232
<i>Vitamin D</i>	0.04 (0.03, 0.04)	-0.01 (-0.02, 0.00)*	-0.01 (-0.02, 0.00)*	0.0039
<i>Vitamin E</i>	0.82 (0.81, 0.83)	+0.03 (0.01, 0.04)*	+0.04 (0.03, 0.06)*	<0.0001
<i>Iodine</i>	0.71 (0.69, 0.73)	-0.04 (-0.06, -0.02)*	0.00 (-0.02, 0.02)	<0.0001
<i>Magnesium</i>	0.87 (0.86, 0.87)	+0.01 (0.00, 0.02)	+0.03 (0.01, 0.04)*	<0.0001
<i>Phosphorus</i>	0.97 (0.97, 0.98)	0.00 (0.00, 0.01)	0.00 (0.00, 0.01)	0.3282
<i>Potassium</i>	0.63 (0.61, 0.65)	-0.02 (-0.04, 0.01)	-0.03 (-0.05, 0.00)	0.0605
<i>Selenium</i>	0.94 (0.93, 0.95)	+0.01 (0.00, 0.02)	0.00 (-0.01, 0.01)	0.0523
<i>Zinc</i>	0.31 (0.29, 0.33)	-0.01 (-0.04, 0.01)	0.00 (-0.03, 0.02)	0.3888
<i>Copper</i>	0.87 (0.86, 0.87)	+0.02 (0.01, 0.03)*	+0.04 (0.02, 0.05)*	<0.0001
<i>Manganese</i>	0.88 (0.87, 0.89)	+0.03 (0.02, 0.04)*	+0.03 (0.02, 0.05)*	<0.0001
<i>Calcium</i>	0.63 (0.61, 0.65)	-0.06 (-0.09, -0.04)*	-0.14 (-0.17, -0.11)*	<0.0001
<i>Iron</i>	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)				
<i>Carbohydrates</i>	0.95 (0.95, 0.96)	-0.01 (-0.02, 0.00)*	0.00 (0.00, 0.01)	0.0007
<i>Protein</i>	0.96 (0.95, 0.96)	0.00 (-0.01, 0.01)	+0.01 (0.00, 0.02)	0.0246
<i>Total fat</i>	0.91 (0.90, 0.92)	+0.01 (-0.01, 0.02)	-0.04 (-0.05, -0.02)*	<0.0001
<i>SFA</i>	0.30 (0.28, 0.31)	+0.09 (0.06, 0.11)*	-0.05 (-0.07, -0.02)*	<0.0001
<i>Sodium</i>	0.57 (0.55, 0.59)	-0.01 (-0.03, 0.02)	+0.04 (0.01, 0.07)*	<0.0001
<i>Sugars without lactose</i>	0.70 (0.68, 0.72)	-0.03 (-0.06, -0.01)*	-0.05 (-0.08, -0.03)*	<0.0001

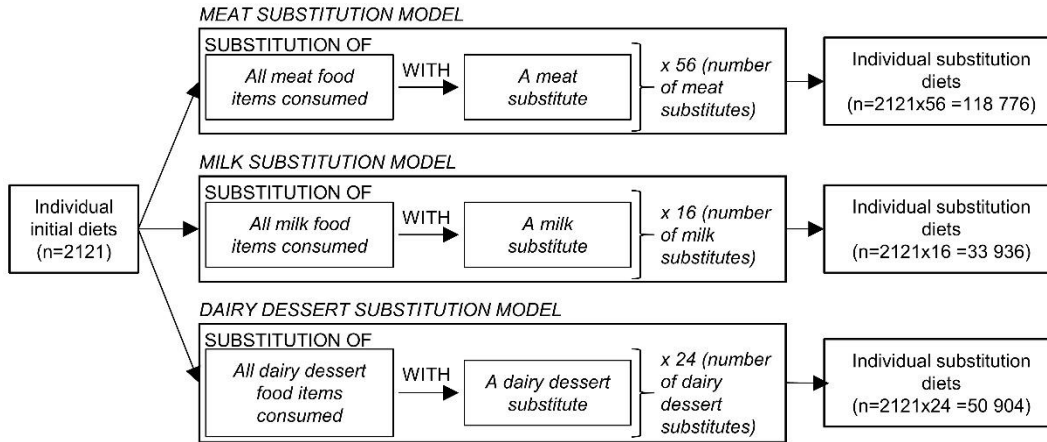
¹ Data from Individual and National Study on Food Consumption Survey 3 (n=2121) where only dairy dessert consumers were selected (n=1666). ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; PANDiet, Probability of Adequate Nutrient Intake; SFA, saturated 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.

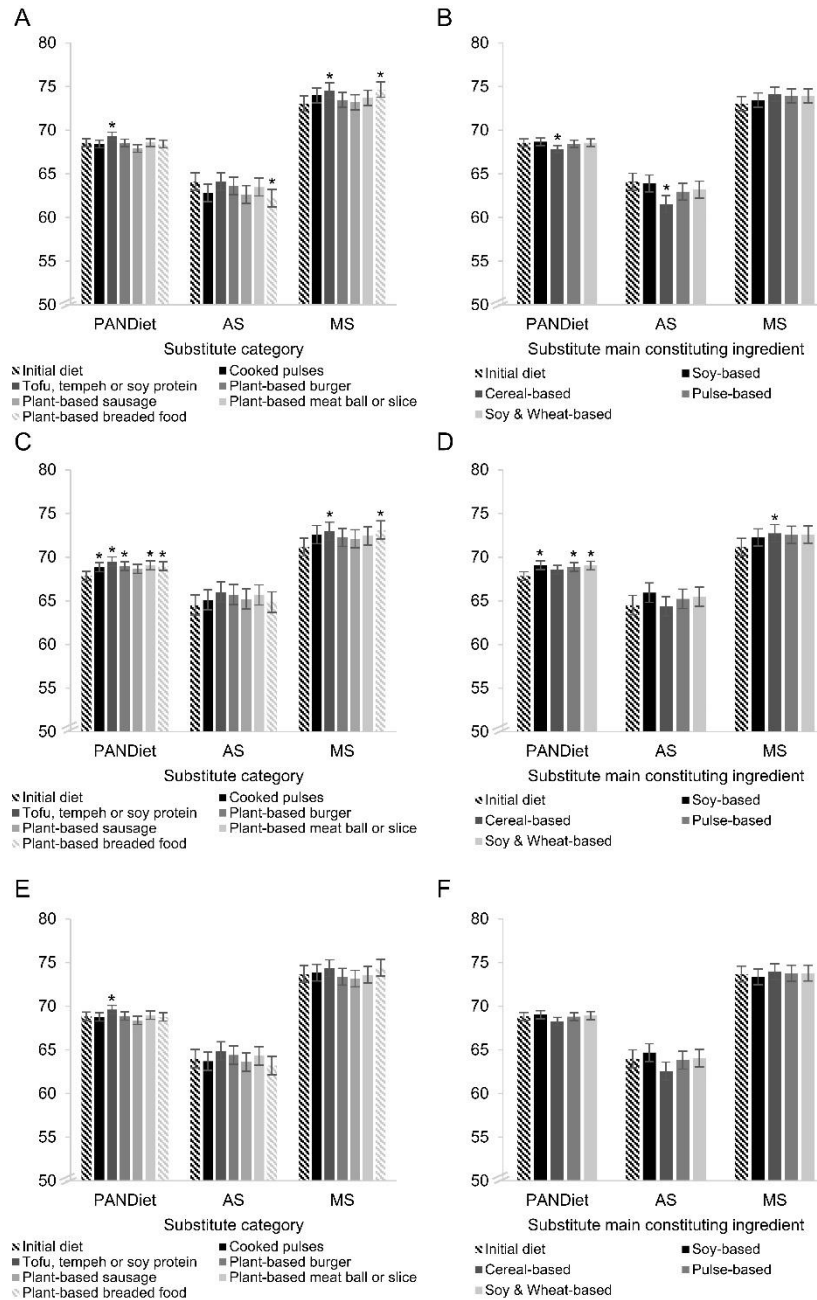
⁴ P for ANOVA tests, post-hoc tests were performed after a Bonferroni correction for multiple comparisons.

Supplementary data.



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

Supplementary data.



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.

Supplementary data.

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