# Respective contribution of ultra-processing and nutritional quality of foods to the overall diet quality: results from the NutriNet-Santé study

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ORIGINAL CONTRIBUTION

# Respective contribution of ultra-processing and nutritional quality of foods to the overall diet quality: results from the NutriNet-Santé study

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## Abstract

**Background** Both the nutritional quality of the foods consumed (as nutrient composition) and their ultra-processed nature have been linked to health risks. However, the respective contribution of each of these correlated dimensions or their synergy to the overall diet quality has been rarely explored.

**Objective** To identify the respective effects of the nutritional quality of the foods consumed, the ultra-processed nature of foods and their cross-effect contributing to the overall quality of the diet.

**Design** Cross-sectional observational study.

**Setting** Web-based French NutriNet-Santé cohort study.

**Participants** Participants in the NutriNet-Santé cohort study with at least three available 24 h records as baseline dietary data ($N = 98\ 454$ participants).

**Main outcome measures** The overall quality of the diet (qualified using the adherence to the 2017 French national nutrition and health dietary recommendations dietary score PNNS-GS2) was broken down into: (1) an effect of the nutritional quality of the foods consumed (qualified using the modified Foods Standards Agency nutrient profile model (underlying the Nutri-Score) dietary index FSAm-NPS DI); (2) an effect of the ultra-processed nature of the foods consumed (qualified using the proportion of ultra-processed foods consumed UPFp using the NOVA classification), and (3) a cross-effect of both dimensions.

**Results** The overall effect from the 'nutritional quality of the foods consumed' (FSAm-NPS DI) was 1.10, corresponding to 26% of the total effect; the overall effect from ultra-processed foods consumption was 1.29, corresponding to 30% of the total effect; and cross-effect between nutritional quality of the foods consumed and ultra-processing was at 1.91, corresponding to 44% of total effects.

**Conclusions** Our study provides support to the postulate that nutritional quality and ultra-processing should be considered as two correlated but distinct and complementary dimensions of the diet.

**Keywords** Nutrient composition · Ultra-processed foods · Diet quality

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## Introduction

Recent developments in nutrition research have highlighted the importance of taking into account the ultra-processed nature of food in its relation to health [1–3]. Initially proposed in Brazil, the concept of ultra-processed foods [4] has developed rapidly into one of the most innovative areas of research in nutrition [3]. While mechanistic hypotheses to explain these associations are still under investigation, the mounting evidence on the topic has prompted several countries to include the reduction of ultra-processed foods in the diet within the framework of dietary guidelines [5–7].

The concept of ultra-processed foods is also highly intertwined with research on the corporate influence of large food companies in defining nutrition policy goals and actions [8–10]. Developed in part to contrast traditional diets made predominantly with unprocessed or minimally processed foods, the concept of ultra-processed foods highlights the share of the diet from 'hyper-palatable, highly marketed' foods, directly referencing how branded, easily accessible products have shifted dietary patterns towards less healthy diets [11, 12].

But support for action against ultra-processed foods has sometimes come in opposition to more established knowledge on the relationship between nutrition and health—framing research on specific nutrients as 'reductionism' [13] claiming that any nutrient-oriented perspective would advance the agenda of the food industry and come at the expense of population health [14, 15]. Others have argued that given that ultra-processed foods are usually higher in calories, sugars and fat, ultra-processing rather than nutrient composition would cover both dimensions [16].

Yet considering diet exclusively under the perspective of ultra-processing may be just as reductionist an approach as considering it only under the perspective of single nutrients.

Diet is one of the most complex exposures in research in human health, as food intake combines effects from nutrients, chemical contaminants, pesticides, level of processing, formulation (i.e. addition of additives), food matrix and probably more yet to be uncovered. Yet while the associations between various nutrients, food groups or dietary patterns have been the object of nutrition research for decades with hundreds of epidemiological, clinical and experimental studies [17–19], we are still in the early years of identifying and disentangling the various effects of these other dimensions of the dietary exposome. More importantly, the relative importance of these various dimensions to characterize diet quality is scarce to non-existent.

The aim of the present paper was to investigate the relative contribution of two dimensions of diets, ultra-processing and nutritional quality of the foods consumed in the characterization of overall diet quality—defined as adherence to dietary guidelines—using a breakdown approach.

## Materials and methods

### Population

NutriNet-Santé is a web-based cohort study which aim is to investigate the associations between nutrition and health [20]. Participants from the adult French population were recruited via multi-media campaigns starting in May 2009. Detailed information is collected at baseline and at least every year thereafter, using self-administered questionnaires regarding sociodemographic characteristics [21], lifestyle, health status (e.g. personal and family history of diseases and drug use), anthropometric data (height, weight) [22, 23], physical activity [24], and diet. Participants with at least three validated 24 h-dietary records ($N$ = 98 454) were included in the analysis.

Electronic informed consent is provided by each participant at baseline. The NutriNet-Santé study is conducted according to the Declaration of Helsinki guidelines. It is registered at ClinicalTrials.gov with number NCT03335644, and is approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB-Inserm) and the "Commission Nationale de l'Informatique et des Libertés" (CNIL n°908450/n°909216).

### Data collection

Dietary intakes are collected at baseline and every 6 months using three non-consecutive 24 h-dietary records, randomly assigned over a 15-day period (2 week-days and 1 one week-end-day). Participants record on the platform all the foods and beverages consumed during the 24-h period, providing details on the portion sizes using validated photographs, standard serving containers or absolute amounts (in g or ml) [25].

Average daily dietary intakes were estimated using all 24 h-dietary records provided during the first 2 years of follow-up (in participants with at least three 24-h records available). Intakes in energy, alcohol, macro-, and micronutrients were assessed using the NutriNet-Santé food composition database (providing the nutritional composition of over 3500 items) [26]. Dietary energy under-reporters were excluded through the Black method, using the Goldberg cut-off [27]. These 24 h-dietary records were validated against an interview by a trained dietitian [28] and against blood and urinary biomarkers [29, 30].

### Nutritional quality of the foods consumed

The FSAm-NPS DI (for modified Food Standards Agency-Nutrient Profiling System Dietary Index), was used to measure the overall nutritional quality of the foods consumed, characterized using the nutrient profile model underpinning the current front-of-pack label Nutri-Score, adopted in France and in several EU countries since 2017 [31]. Briefly, the FSAm-NPS at the food level provides an overall assessment of the nutritional quality of the food or beverage based on its content for 100 g or ml in unfavourable elements (energy, sugars, saturated fat and sodium) and favourable elements (proteins, fibres, percentage of fruit, vegetables, nuts, legumes and vegetable oils (olive, canola and nut)). Unfavourable elements are allocated + 0–10 points while favourable elements − 0–5 points, the sum of which yields an overall estimate ranging theoretically from − 15 to + 40 [32]. Hence, the higher the FSAm-NPS, the lower the nutritional quality of the food or beverage. At the diet level, the FSAm-NPS DI is computed as the energy-weighted mean of the foods consumed by the individual [33]. The FSAm-NPS has been found to provide an adequate reflection of the nutritional quality of the diet, and has been related to a number of health outcomes, including mortality, cancer, cardiovascular disease and metabolic syndrome [34–37]. Detailed information on the development and validation of the FSAm-NPS DI can be found elsewhere [33, 38].

### Proportion of ultra-processed foods in the diet

The proportion of ultra-processed products in the diet (UPFp) was assessed using the NOVA classification of foods, applied to the foods consumed by the individual. Briefly, NOVA classifies foods into four categories according to the degree and purpose of processing, from NOVA1—unprocessed and minimally processed foods, to NOVA4—ultra-processed foods (UPFs) [4]. UPFs are defined as food undergoing extensive physical or chemical transformation, including industrial ingredients (e.g. high fructose corn syrup) and/or containing several additives for cosmetic purposes (colouring, texturing, etc.). UPF consumption (as a percentage in the diet) has been associated to a number of nutrition-related diseases, including obesity, diabetes and mortality [39–41]. Foods classified as NOVA 4—UPFs—were identified, and their contribution to the diet (in absolute quantities and proportion in weight—UPFp) was computed. Hence, a higher UPFp represents a higher proportion of UPFs in the diet, corresponding to a more processed diet. Detailed information on the development of UPFp has been published elsewhere [42, 43].

### Overall diet quality

Overall diet quality was assessed using an a-priori score of adherence to the 2017-updated French National food-based dietary guidelines, the PNNS-GS2 score (for Programme National Nutrition Santé (National Nutrition and Health)—Guideline Score 2) [45]. Briefly, the PNNS-GS2 evaluates the degree of adherence to the French food-based dietary guidelines, taking into account the 13 main recommendations stated in the scientific document from the High Council for Public Health [44]. The 13 components include (1) food groups to encourage, as adequacy components: fruits and vegetables, nuts, legumes, whole-grain foods, milk and dairy products, fish and seafood, added fats (preference towards plant-based oils); (2) and food groups to limit, as moderation components: red meat, processed meat, sugary foods, sweet-tasting beverages, alcoholic beverages and salt. Scoring was built for adequacy components (0 to 1 point—healthier food groups) and moderation components (-1 to 0 points—less healthy food groups). PNNS-GS2 was computed for each participant as the component sub-score multiplied by its associated weight and divided by its maximum absolute value and then summing up over all components for a maximum total of 14.25. Higher PNNS-GS2 reflects a higher adherence to the 2017 French food-based dietary guidelines. Detailed description of the PNNS-GS2 score is available elsewhere [45].

### Statistical analysis

Quintiles of PNNS-GS2 were computed, and the average FSAm-NPS DI and UPFp in quintiles 1 and 5 were used as input data in a breakdown analysis detailed below and based on a counterfactual exercise [46]. Quintile 1 of PNNS-GS1 corresponds to a low adherence to food-based dietary guidelines, quintile 5 of PNNS-GS2 corresponds to a higher adherence to food-based dietary guidelines.

To disentangle the effects between ultra-processing (assessed by the UPFp using the NOVA 4 category) and nutritional quality of the foods consumed (assessed by the FSAm-NPS DI) on the characterization of overall diet quality (outcome variable) the variation of the diet quality between the two extreme quintile individuals of mPNNS-GS2 (Q1 and Q5, quintile 5—higher adherence considered as the reference) was decomposed into three components:

1. A 'nutritional quality of foods consumed' effect that is the difference in overall diet quality between Q1 and Q5 that results from the difference in the nutritional quality of the foods consumed. Considering the overall orientation of the FSAm-NPS DI, with higher scores reflecting lower nutritional quality of the foods consumed, a positive difference reflects a higher consumption of foods with low nutritional quality in participants with lower adherence to food-based dietary guidelines.
2. An 'ultra-processed foods consumed' effect that is the difference in overall diet quality between Q1 and Q5 resulting from the difference in the ultra-processed nature of the foods consumed. Considering the construction of UPFp as a variable, a positive difference reflects a higher proportion of UPFp in participants with lower adherence to food-based dietary guidelines.
3. The 'cross-effect' of the two, which is the residual variation in overall diet quality between Q1 and Q5 of PNNS-GS2 associated with the simultaneous variation of the

nutritional quality of foods and their ultra-processed nature.

Hence, in the hypothesis that all differences in the overall diet quality would be explained by the consumption of ultra-processed foods, effects of the 'nutritional quality of the foods consumed' would be null; conversely, should all differences in the overall diet quality be associated with the nutritional quality of the foods consumed, effects of the 'ultra-processed foods consumed' would be null.

From a computational standpoint, differences between quintiles were investigated breaking down the diet into 36 food groups. For each food group, the average 'nutritional quality of foods consumed' was computed as the average FSAm-NPS DI for the given food group in Q1 and Q5 of PNNS-GS2; the 'UPF' was computed as the percentage UPFp from the given food group in Q1 and Q5 of PNNS-GS2. The outcome diet quality variable was constructed as a multiplication between the average nutritional quality of the foods consumed in each food group and the average contribution of each food group to the total ultra-processed food consumption in Q1 and Q5 of PNNS-GS2, as FSAm-NPS DI × UPFp. Differences between Q1 and Q5 of PNNS-GS2 were computed for each variable: FSAm-NPS DI, UPFp and FSAm-NPS DI × UPFp. Decomposition in effects of 'nutritional quality of the foods consumed' 'ultra-processed foods consumed' and 'cross-effects' were computed at the food group level. Finally, total differences and effects were obtained as the sum across food group, as described in the following mathematical expression:

$$\Delta\left[FSAm - NPSDI \times UPFp\right]_{(1-5)} = \sum_{i=1}^{n} FSAm - NPSDI \times UPFp_{i(1-5)}$$

$$= \sum_{i=1}^{n} [UPFp_{i5}\Delta FSAm - NPSDI_{i(1-5)}$$

$$+ \Delta UPFp_{i(1-5)} FSAm - NPSDI_{i5} + \Delta UPFp_{i(1-5)} \Delta FSAm - NPSDI_{i(1-5)}]$$

where $i = 1$, $n$ are the food groups, $\Delta \mathrm{UPFp}_{i(1-5)}$ is the variation in the UPFp of each food group between the first and last quintile of PNNS-GS2, $\Delta$FSAm-NPS $\mathrm{DI}_{i(1-5)}$ is the variation in the FSAm-NPS DI of each food group between the fst and last quintile of PNNS-GS2, $\mathrm{UPFp}_{i5}$ is the average UPFp of each food group in quintile 5 of the PNNS-GS2 and FSAm-NPS $\mathrm{DI}_{i5}$ is the average FSAm-NPS DI of each food group in quintile 5 of the PNNS-GS2.

Considering that the unit for the FSAm-NPS DI (and, therefore, the FSAm-NPS DI × UPFp outcome variable) cannot be translated as a straightforward amount of nutrient intakes and/or food consumption, the interpretation of results relies mainly on the relative contribution of each of the effects for total effects and on the magnitude of effects relative to total effects for specific food groups.

Of note, while there is a variability in the nutritional quality of the foods within all food groups, some food groups are either all ultra-processed (e.g. sugar-sweetened beverages) or non-ultra-processed (e.g. fruits), in which case ultra-processing effect is by construction null. 95% uncertainty intervals were obtained with 500 bootstrap iterations.

Sensitivity analyses explored the impact of the number of food groups into which the diet is decomposed on results, using 27 food groups instead of 36. Additional sensitivity analyses explored ultra-processed food consumption expressed in absolute quantities rather than relative contribution of each food group.

## Results

Total sample included 98 454 participants with at least three dietary records available (Supplemental Fig. 1). Characteristics of the participants included in the analysis is presented in Supplemental Table 1. Overall, the difference in the proportion of ultra-processed foods consumed between the first and last quintiles of PNNS-GS2 score was 6.98 percentage points (from 20.04% of UPFp in quintile 1 to 13.06% UPFp in quintile 5). The corresponding difference was 3.70 for FSAm-NPS DI (from an FSAm-NPS-DI of 8.09 in quintile 1 to an FSAm-NPS DI of 4.39 in quintile 5—i.e. higher FSAm-NPS DI correspond to lower nutritional quality of the foods consumed in participants with lower adherence to food-based dietary guidelines).

Total 'diet quality' (as FSAm-NPS DI × UPFp) difference between Q1 and Q5 was 4.31 percentage points. The overall effect from the 'nutritional quality of the foods consumed' (FSAm-NPS DI) was 1.10 (95% uncertainty interval: 1.08–1.12), corresponding to 26% of the total effect; the overall effect from ultra-processed foods consumption was 1.29 (1.25–1.31), corresponding to 30% of the total effect; and cross-effects between nutritional quality of the foods consumed and ultra-processing was at 1.91 (1.85–1.95), corresponding to 44% of total effects (Fig. 1).

The food groups which were major drivers for all effects were processed meat (0.24 associated with nutritional quality, 0.23 associated with ultra-processing and 0.92 cross-effects) and pizza and quiche (0.10 associated with nutritional quality, 0.20 associated with ultra-processing and 0.16 cross-effects) (Table 1). In practice, this means that the difference observed in overall diet quality between low-adherence and high-adherence to guidelines participants for processed meat is driven as much by a choice of processed meat with higher salt and/or fat content (nutritional quality of the foods effects) as by a selection of ultra-processed products, the cross-effect of the simultaneous choice of products both

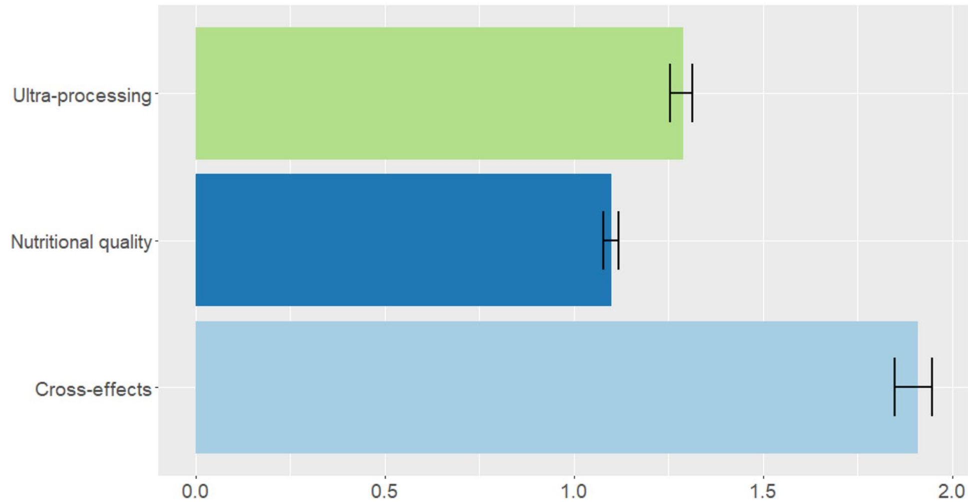


**Fig. 1** Decomposition of effects between nutritional quality of the foods consumed, ultra-processed foods consumption and cross-effects—absolute values

of lower nutritional quality and ultra-processed playing a much larger role.

Nutritional quality effects were further driven by choices in prepared meals (0.14), biscuits and cakes (0.12). This means that for these groups, the differences in the overall diet quality observed between low- and high-adherence participants were mainly due to a selection of products with lower nutritional value within the group. Ultra-processed foods effects were further driven by choices in biscuits and cakes (0.26) and sugar-sweetened beverages (0.14). This means that for these groups, the differences in the overall diet quality observed between low- and high-adherence participants were mainly due to a selection of ultra-processed products within the group. Cross-effects were further driven by choices in sugar-sweetened beverages (0.41). This means that for sugar-sweetened beverages, the simultaneous effects of the selection of ultra-processed products with lower nutritional value were also of larger importance.

Sensitivity analyses using quantity of ultra-processed foods consumed rather than contribution or using 27 food groups rather than 36 yielded similar results (Supplemental Table 2).

## Discussion

Overall, our results show that the nutritional quality of the foods consumed and their ultra-processed nature are two dimensions that contribute to a substantial degree to the healthiness of the diet, measured using a-priori-based approaches of adherence to dietary recommendations. More importantly, the most important effects observed were cross-effects between nutritional quality of the foods consumed and ultra-processed foods, unveiling synergistic effects of both dimensions.

The FSAm-NPS DI has been found to be associated with diet quality, with healthier diets associated with higher consumption of fruit and vegetables, whole-grain products and fish and lower consumption of alcoholic and sugar-sweetened beverages and snacking products [33, 38]. Similarly, UPFp has been found to be associated with similar dietary patterns [43]. At the food level, nutritional quality and ultra-processing are associated, with higher contents in sugar, fat or salt being found in ultra-processed product on average. As an example, 85.6% of foods classified as 'less healthy' in the front-of-pack label Nutri-Score are considered ultra-processed [47].

However, this correlation is not collinearity, and non-UPFs can still be high in sugars, salt or fat (e.g. traditional cheese, home-made cakes) and conversely, some foods low in harmful nutrients can be ultra-processed (e.g. artificially sweetened beverages).

Calls for governments to regulate the ultra-processing of foods through marketing restriction or labelling have been issued [48], and while authors do not address directly the complementarity of the two dimensions, they recognize that the final aim for food systems is of ultra-processed foods to 'be replaced by processed foods with limited levels or absence of added salt, sugar or unhealthy fats'. Tackling the issue will indeed necessitate policies that cover both the nutrient composition of the food, and its ultra-processed nature.

While numerous studies have shown that ultra-processed food consumption or the nutritional quality of foods consumed separately were associated with dietary quality, our study is the first to investigate the contribution of each dimension to the overall quality of the diet, providing insights into the relative contribution of each and their cross-effects.

Limitations to this study should be acknowledged. First, we used adherence to French dietary guidelines as a benchmark for diet quality, when other *a-priori* scores of diet quality could also have been used. However, this

**Table 1** Decomposition of the differences observed between quintile 1 (low adherence) and quintile 5 (high adherence) of PNNS-GS2 as effects associated with the nutritional quality of the foods consumed (FSAm-NPS DI), effects associated with ultra-processed food consumption (UPF) and cross-effects—36 food groups breakdown

| | Effects associated with nutritional quality (FSAm-NPS DI) | Effects associated with ultra-processed food consumption (UPF) | Cross-effects |
|---|---|---|---|
| Offals | 0.00 | 0.00 | 0.00 |
| Biscuits and cakes | 0.12 | 0.26 | 0.06 |
| Artificially sweetened beverages | 0.00 | 0.00 | 0.00 |
| Non-sugared beverages | – 0.01 | 0.00 | 0.00 |
| Sugar-sweetened beverages | 0.05 | 0.14 | 0.41 |
| Cereal products | 0.00 | 0.00 | 0.00 |
| Breakfast cereals | – 0.03 | – 0.03 | 0.01 |
| Processed meat | 0.24 | 0.23 | 0.92 |
| Chocolate products | 0.02 | 0.05 | 0.01 |
| Confectionery | 0.03 | 0.03 | 0.01 |
| Dairy desserts | 0.09 | 0.05 | 0.02 |
| Cheese | 0.01 | 0.02 | 0.01 |
| Fruit | 0.00 | 0.00 | 0.00 |
| Dried fruit | 0.00 | 0.00 | 0.00 |
| Ice cream | 0.02 | 0.03 | 0.02 |
| Fruit juice | 0.00 | 0.02 | 0.00 |
| Vegetables | 0.05 | 0.01 | – 0.01 |
| Legumes | 0.01 | 0.00 | 0.00 |
| Fats and oils | 0.02 | 0.00 | 0.00 |
| Fruit nectars | 0.00 | 0.00 | 0.00 |
| Nuts | 0.00 | 0.00 | 0.00 |
| Eggs | 0.00 | 0.00 | 0.00 |
| Bread | 0.06 | 0.00 | 0.00 |
| Pizza | 0.10 | 0.20 | 0.16 |
| Prepared meals | 0.14 | 0.06 | 0.09 |
| Fish and seafood | 0.00 | 0.00 | 0.00 |
| Potatoes and tubers | 0.01 | 0.01 | 0.03 |
| Vegetarian substitutes | 0.00 | 0.00 | 0.00 |
| Appetizers | 0.02 | 0.02 | 0.02 |
| Milk and dairy | 0.03 | 0.02 | – 0.01 |
| Sandwich | 0.02 | 0.02 | 0.06 |
| Soups | 0.01 | 0.00 | 0.00 |
| Meal substitutes | 0.00 | 0.00 | 0.00 |
| Meat | 0.02 | 0.03 | 0.05 |
| Pastries | 0.03 | 0.05 | 0.03 |
| Sauces and dressings | 0.03 | 0.05 | 0.02 |
| Total absolute effects | **1.10** | **1.29** | **1.91** |

Total effects are presented in a bold font

*a-priori* score is validated and relies on recommendations based on effects of dietary components on health [45]. Second, as the FSAm-NPS DI is computed using energy weightings, the effect of some food groups providing little energy—like artificially sweetened beverages—could have been underestimated.

## Conclusion

Our study provides support to the contention that nutritional quality and processing should be considered as two correlated but distinct and complementary dimensions of the diet. As such, interventions to improve diet—whether reformulation strategies, food labelling, marketing restrictions—should include both dimensions, relying on the potentially synergistic effects obtained.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s00394-022-02970-4.

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**Author contributions** CJ, PG, SH and EKG conceptualized the study and defined the analytical strategy. EKG, JB and CJ conducted the statistical analysis. CJ drafted the manuscript. CJ, JB, MF, SH, PG, BS, EC, VAA, MT and EKG critically helped in the interpretation of results, read and revised the manuscript for important intellectual input. All authors have read and approved the final manuscript. CJ and EKG have primary responsibility for the final content.

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**Data availability statement** If you are a researcher of a public institution, you can submit a collaboration request including your institution and a brief description of your project to collaboration@etude-nutrinet-sante. All requests will be reviewed by the steering committee of the NutriNet-Santé study. A financial contribution may be requested. If the collaboration is accepted, a data access agreement will be necessary and appropriate authorizations from the competent administrative authorities may be needed. In accordance with existing regulations, no personal data will be accessible.

## Declarations

**Conflict of interest** The authors report no conflicts of interest.

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