Contrary to ultra-processed foods, the consumption of unprocessed or minimally processed foods is associated with favorable patterns of protein intake, diet quality and lower cardiometabolic risk in French adults (INCA3)

Marion Salomé, Laura Arrazat, Juhui Wang, Ariane Dufour, Carine Dubuisson, Jean-Luc J.L. Volatier, Jean-François Huneau, François Mariotti

This is the "postprint" version, i.e. the authors' version that has been accepted for publication, of the article by Salomé et al., finally published in European Journal of Nutrition, published online: 8 May 2021.

Full reference is:

Salomé, M., Arrazat, L., Wang, J. et al. Contrary to ultra-processed foods, the consumption of unprocessed or minimally processed foods is associated with favorable patterns of protein intake, diet quality and lower cardiometabolic risk in French adults (INCA3). Eur J Nutr (2021).

The edited final article can be found on the publisher website, at: https://doi.org/10.1007/s00394-021-02576-2

Contrary to ultra-processed foods, the consumption of unprocessed or minimally processed foods is associated with favorable patterns of protein intake, diet quality and lower cardiometabolic risk in French adults (INCA3).

Marion Salomé[1§], Laura Arrazat[1§], Juhui Wang[1], Ariane Dufour[2], Carine Dubuisson[2], Jean-Luc Volatier[2], Jean-François Huneau[1], François Mariotti[1*]

[1]Université Paris-Saclay, AgroParisTech, INRAE, UMR PNCA, 75005, Paris, France

[2]Risk Assessment Department, Methodology and Survey Unit, French Agency for Food, Environmental and Occupational Health & Safety (ANSES), 14 rue Pierre et Marie Curie, 94701 Maisons-Alfort Cedex, France

§ These authors contributed equally to this work.

Short title: Ultra-processed foods, protein intake and diet quality

* Corresponding author: François Mariotti, 16 rue Claude Bernard, 75005 Paris, France, francois.mariotti@agroparistech.fr

ORCID number:

Jean-François Huneau : 0000-0001-7336-2617 ; François Mariotti: 0000-0002-4516-3853

Acknowledgments

The authors would like to thank Benjamin Allès (Nutritional Epidemiology Research Team (EREN) at Université Paris 13, France) for his scientific support in constructing the NOVA database and Emmanuelle Kesse-Guyot (Nutritional Epidemiology Research Team (EREN) at Université Paris 13, France) for her scientific contribution to the constitution of the disease mortality database for the EpiDiet model.

List of abbreviations

ANSES, French Agency for Food, Environmental and Occupational Health and Safety; AS, Adequacy Subscore; BI, Berry-Index; BI-ABF, Berry-Index – Animal-based families; BI-PBF, Berry-Index – Plant-based families; CIQUAL, French Centre for Information on Food Quality; EpiDiet, Evaluate the Potential Impact of a Diet; hPDI, healthful Plant-based Diet Index; INCA3, Third Individual and National Study on Food Consumption Survey; MPF, unprocessed/minimally processed foods; MPFp, proportion of total energy intake from MPF; MS, Moderation Subscore; PANDiet, Probability of Adequate Nutrient Intake; PDI, Plant-based Diet Index; PF, processed foods; PFp, proportion of total energy intake from PF; uPDI, unhealthful Plant-based Diet Index; UI, uncertainty interval; UPF, ultra-processed foods; UPFp, proportion of total energy intake from UPF.

Declarations

Funding

M Salomé's PhD fellowship is currently being funded by a research contract with Terres Univia, the French Interbranch organization for plant oils and proteins. F Mariotti is the scientific leader of this contract.

Conflicts of interest/Competing interests

The authors declare that they have no competing interests.

Ethics approval

The INCA3 study was carried out in accordance with the Declaration of Helsinki guidelines and was approved by the 'Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé' (Advisory Committee on Information Processing in Health Research).

Consent to participate

For the data collection of the INCA3 survey, oral consent was obtained, witnessed and formally recorded from participants.

Consent for publication

Not applicable

Availability of data and materials

The datasets of the INCA3 survey are available at data.gouv.fr. Data sets generated during the current study are available from the corresponding author on reasonable request.

Code availability

Custom code are available from the corresponding author on reasonable request.

Authors' contributions

Marion Salomé, Laura Arrazat and François Mariotti designed research; Marion Salomé, Laura Arrazat and Juhui Wang conducted research; Ariane Dufour, Carine Dubuisson and Jean-Luc Volatier provided the databases essential for the research; Jean-François Huneau provided methodological support. Marion Salomé and Laura Arrazat analyzed data and performed statistical analysis; Marion Salomé, Laura Arrazat, Juhui Wang and François Mariotti interpreted the results; Marion Salomé, Laura Arrazat, Juhui Wang and François

Mariotti wrote paper; Marion Salomé and François Mariotti had primary responsibility for the final content and all authors read and approved the final manuscript.

Abstract

Purpose. While the consumption of ultra-processed foods is steadily increasing, there is a growing interest in more sustainable diets that would include more plant protein. We aimed to study associations between the degree of food processing, patterns of protein intake, diet quality and cardiometabolic risk.

Methods. Using the NOVA classification, we assessed the proportion of energy from unprocessed/minimally processed foods (MPFp), processed foods (PFp) and ultra-processed foods (UPFp) in the diets of 1774 adults (18-79y) from the latest cross-sectional French national survey (INCA3, 2014-2015). We studied the associations between MPFp, PFp and UPFp with protein intakes, diet quality (using the PANDiet scoring system, the global (PDI), healthful (hPDI) and unhealthful (uPDI) plant-based diet indices) and the risk of cardiometabolic death (using the EpiDiet model).

Results. MPFp was positively associated with animal protein intake and plant-protein diversity, whereas PFp was positively associated with plant protein intake and negatively with plant-protein diversity. The PANDiet was positively associated with MPFp (β=0.14, $P<0.0001$) but negatively with UPFp (β=-0.05, $P<0.0001$). These associations were modified by adjustment for protein intakes and plant-protein diversity. As estimated with comparative risk assessment modeling between extreme tertiles of intake, mortality from cardiometabolic diseases would be decreased with higher MPFp (e.g. by 31% for ischemic heart diseases) and increased with UPFp (by 42%) and PFp (by 11%).

Conclusions. In the French population, in contrast with UPFp, a higher MPFp was associated with a higher animal protein intake, a better plant-protein diversity, a higher diet quality and a markedly lower cardiometabolic risk.

Keywords: Ultra-processed Foods, Dietary Plant Protein, Dietary Animal Protein, Diet Quality, Plant-Based Diet.

Introduction

The development of industrially-produced foods is reshaping our food system and therefore influencing diets worldwide. At present, in many high-income countries such as the USA or UK, ultra-processed foods (UPF) (usually defined as convenient food and drink products with high industrially processing and generally many ingredients increasing shelf life and palatability [1, 2]), contribute more than half of dietary energy intake [3, 4]. In middle-income countries, this percentage is lower but is seeing a sharp rise [5]. The UPF available on the market are usually rich in energy, saturated fats, sugar and salt [4, 6]. They also have lower protein content than less processed foods and diets high in UPF have been associated with lower protein intake [4, 7].

In high-income countries, animal-based foods are the major source of protein but also have an important environmental footprint [8, 9]. Therefore, with regard to the global environmental impacts of the food system, a plant-based protein transition seems necessary to achieve more sustainable diets [10, 11].

However, although plant-based diets are known to have a positive impact on health [12–14], plant-based food products differ in terms of their quality and contribution to current diets. In particular, it has been shown that the associations between plant-based diets and incidences of coronary heart disease or type 2 diabetes are dependent on the types of plant foods consumed, whether they are considered as healthy plant foods (e.g. whole grains, fruits, etc.) or less-healthy plant foods such as more processed foods (e.g. sweetened beverages, fries, etc.) [15, 16]. Furthermore, it has been recently reported that some vegetarians diets are associated with high consumption of ultra-processed foods [17] suggesting that the benefit of diets high in plant-based foods may depend on the actual share of ultra-processed foods.

Indeed, an overall increase in the consumption of UPF has been thought to play a major role in the pandemics of obesity and diet-related chronic diseases [18, 19]. Many studies have recently reported associations between the consumption of UPF and non-communicable diseases [20–23] or mortality rates [24, 25]. An inpatient randomized controlled trial, where ultra-processed and unprocessed diets were matched for presented energy and macronutrients, reported that the consumption of ultra-processed foods resulted in a higher energy intake (by ~500 kcal) and a 0.9 kg increase in body weight [26].

Therefore, the aim of this study was to investigate the consumption of foods with different processing degrees and the associated intake of animal or plant protein, the diet quality and predicted long-term health. We hypothesized that the degree of processing of foods in the diet is differentially associated with plant/animal protein sources, and that it could explain the resulting association with the diet quality and cardiometabolic health.

Subjects and Methods

Population and dietary data

The population studied was derived from the third Individual and National Study on Food Consumption Survey (INCA3), performed in mainland France in 2014-2015 [27]. INCA3 is a nationwide and representative survey and its methodology and design are fully described elsewhere [28]. Of the 2121 adults (18-79y) who completed the whole protocol of the INCA3 survey, under-reporting participants were excluded from their basal metabolic rate estimated using the Henry equation [29] and the cutoff points proposed by Black [30]. The final sample thus contained 1774 adults (749 males and 1025 females) (Supplementary Figure S1).

Food and beverage consumption was recorded using three nonconsecutive 24-h dietary recalls (two on weekdays, one at the week-end) over a 3-wk period. Dietary recalls were carried out by phone by professional investigators, assisted by the dietary software GloboDiet [31], and participants were not aware of the days of recall so they could not anticipate it. The nutrient contents of the foods and beverages were extracted from the 2016 database generated by the French Center for Information on Food Quality (*Centre d'Information sur la Qualité des Aliments; CIQUAL)* [32]. Food items were classified into groups and sub-groups. Individual sociodemographic characteristics were collected from face-to-face and self-administered questionnaires [28].

Degree of food processing

The NOVA classification [1] was applied to assess the degree of food processing for 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. The present study focused on MPF, PF and UPF consumption.

For most of the food items consumed, the method of preparation was known. 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 according to its degree of processing. If the method of preparation was unknown for a food item eaten by a participant, the most common method of preparation observed in the population for this particular food was assigned. For each participant the proportion (%) of total energy intake from unprocessed/minimally processed foods (MPFp), processed culinary ingredients, processed foods (PFp) and ultra-processed foods (UPFp) was calculated.

Identification of protein sources

Using the decomposition of food items into ingredients, the protein origin of each ingredient was assigned to a food family. Food families were either plant-based (“Refined grains”, “Whole grains”, “Legumes”, “Nuts and seeds”, “Fruits”, “Vegetables”, “Potatoes” and “Other plant foods”) or animal-based (“Red meat”, “Poultry”, “Fish”, “Processed meat”, “Other meats”, “Eggs”, “Cheeses”, “Milk”, “Yogurt”, and “Other dairy products”).

The contribution of each plant-based family to plant protein intake was characterized using the Berry-Index – Plant-based families (BI-PBF) plant protein diversity index, as previously described [33]. The Berry-Index was used in previous studies to evaluate the evenness of the distribution of total energy intake among food groups [34, 35]. The BI-PBF index is defined as $1 - \sum_{i=0}^{n} {s_i}^2$, where s_i is the share of plant-based family *i* in plant-protein intake, and *n* is the total number of plant-based families. A higher score reflects greater diversity with a more balanced contribution of each plant-based family to plant protein intake. Likewise, the Berry-Index – Animal-based families (BI-ABF) was used to assess the diversity of the contribution of animal-based families to animal protein intake.

Nutrient adequacy of the diet

The nutrient adequacy of the diet was assessed using version 3.1. of the Probability of Adequate Nutrient Intake (PANDiet) scoring system [36, 37], based mainly on the dietary reference intake from the 2016 opinion issued by the French Agency for Food, Environmental, and Occupational Health and Safety (ANSES) [38]. The reference values were adapted to take account of the different nutrient requirements of adults aged over 65y [39]. The PANDiet score is the mean of the adequacy subscore (AS) and the moderation subscore (MS). AS is the mean of the probabilities of adequacy for 27 nutrients for which the usual intake should be above a reference value, multiplied by 100. MS is the mean of the probabilities of adequacy for six nutrients for which an upper bound reference value exists, multiplied by 100 (Supplementary Table S1). Each probabilities of adequacy are calculated using the mean intake, the intra-individual (i.e. day-to-day) variability of intake, the inter-individual variability and the nutrient reference value [36]. The PANDiet score ranges from 0 to 100 and the higher the score, the better the overall nutrient adequacy of the diet.

Adherence to a plant-based diet

The Plant-based Diet Indices, developed by Satija et al. [16], were used to assess how much a diet was based on plant-based foods. The PDIs comprise three indices which distinguish plant-based foods according to their impact on health: the overall plant-based diet index (PDI), the healthful plant-based diet index (hPDI) and the unhealthful plant-based diet index (uPDI). To calculate these scores, foods were assigned to healthy plant food groups (whole grains, fruits, vegetables, nuts, legumes, vegetable oils and tea/coffee), less healthy plant food groups (fruit juices, sugar-sweetened beverages, refined grains, potatoes and sweets/desserts), or animal food groups (animal fats, dairy, eggs, fish/seafood, meat and miscellaneous animal-based foods). The consumption of each food group was calculated for each individual. The PDI gives more points to high consumers of plant-based food groups than to those with a high consumption of animal food groups. The hPDI gives more points to high consumers of healthy plant food groups and fewer points to high consumers of less healthy plant food groups and animal food groups. Symmetrically, the uPDI gives more points to high consumers of less healthy plant food groups than to high consumers of healthy plant food groups or animal food groups [15] (Supplementary Table S2).

Predicting the impact on cardiometabolic death

The impact of dietary patterns on cardiometabolic death was evaluated using the EpiDiet (Evaluate the Potential Impact of a Diet) model, which is a simulation-based nutritional and epidemiologic model that implements the Comparative Risk Assessment framework [11, 40], enabling prediction of the positive or negative impact on long-term health that would result from changes in the diet for an individual, group or population, as previously described [41]. The EpiDiet model was written in Python and deployed on a High Performance Computing framework. Two sources of data were used to develop the EpiDiet model. The first source of data was the relative risk estimates that relates the nutritional factors to the disease endpoint and that have been reported in validated international meta-analyses [42–44]. Disease scope was defined according to the International Statistical Classification of Diseases and Related Health Problems [45]. Second, the French population demographics and mortality in 2014 (being the year of the dietary survey) were used, provided respectively by the National Institute of Statistics and Economic Studies (INSEE) [46], and the Epidemiological Centre on Medical Causes of Death (CEPIDC) [47]. Nutritional factors and diseases included in the EpiDiet model are presented in Supplementary Figure S2. In this study, only coronary heart diseases, cerebrovascular diseases and diabetes were considered. The EpiDiet model therefore evaluated the potential impacts of dietary changes associated with patterns of intake according to food processing on the number of death from these diseases in the French population, if the whole population was adopting the dietary change.

Statistical analysis

The population was stratified into tertiles in three different ways according to the proportion of total energy intake from MPF (MPFp), PF (PFp) or UPF (UPFp) in their diet. Cross-classified frequencies of the MPFp, PFp and UPFp tertiles are presented in Supplementary Table S3.

Categorical variables are presented as percentages, and differences across the tertiles were assessed by χ^2 test. Continuous variables are presented as means ± SEM, adjusted for the season of recall, in order to take into account that the degree of processing may depend on the seasonality of food products. Differences across the tertiles of each NOVA group or between the third tertiles of MPFp, PFp and UPFp within the general population were assessed by ANOVA adjusted for the season of recall. Protein intakes were adjusted for total energy intake using the residual method [48]. The weighting schemes proposed in INCA3 were used to account for the complex survey design.

Associations between diet quality indices (PANDiet and PDIs) and the proportions of total energy intake from MPF, PF and UPF were analyzed using multiple linear regression models. First, the proportions of processed culinary ingredients, PF and UPF were included in the same model in order to study their associations with diet quality indices independently of each other. In this way, associations could be interpreted as the effect of substitution of one of these variables with the proportion of MPF (not included in the model and therefore taken as the reference). Associations with diet quality indices were then estimated separately for the proportions of total energy intake from MPF, PF and UPF, with a further adjustment for protein intakes and/or plant protein diversity. The potential confounding factors included in the models, because of their associations with NOVA groups, were total energy intake (continuous), age (continuous), sex (two levels), educational level (four levels), occupational status (eight levels), city size (five levels), perception of financial status (six levels), season of record (four levels), region of France (five levels) and matrimonial status (five levels).

For each NOVA group (MPF, PF and UPF), the EpiDiet model was implemented to compare the first tertile (baseline scenario) with the third tertile (counterfactual scenario). The number of deaths potentially avoided (or, conversely, added) were simulated among French adults from cerebrovascular, ischemic heart diseases and diabetes if the dietary patterns of the French population would shift from the baseline to the counterfactual scenario, according to the number of deaths observed in 2014 in the French population. The population was stratified 5-year age bands and sex in order to take better account of the disparities regarding diet, diseases and relative risks between groups. All foods and nutrients (except sodium) were adjusted for total energy intake using the residual method [49], while fatty acids were expressed as a percentage of total energy intake. Sensitivity analyses were performed to determine the weight of each nutritional factor in the estimation of number of deaths [50].

All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA.), except the EpiDiet model that was performed with Python version 3.7.1. Significance was set at $P<0.05$.

Results

In the overall population, MPF contributed to 32.8 ± 12.1% of energy intake, PF to 24.9 ± 12.2% of energy intake and UPF to 30.6 ± 15.8% of energy intake (data not shown).

Participants in the third tertile of MPFp, compared to those in the first tertile, were more likely to be women (57.0% vs 43.4%) and aged over 50y (53.2% vs 29.4%). Participants in the third tertile of PFp, compared to those in the first tertile, were more likely to be men (62.2% vs 40.1%) and aged over 50y (57.2% vs 31.9%). Participants in the third tertile of UPFp, versus those in the first tertile, were more likely to be younger than 35y (46.2% vs 8.7%) with no difference regarding sex (Supplementary Table S4).

Degree of processing and protein consumption

Compared to the first tertile of MPFp, individuals in the third tertile consumed more animal protein (61.0 g/day vs 51.1 g/day) and plant protein (26.4 g/day vs 25.7 g/day) and had a lower contribution of plant protein in the diet (31.2% of total protein intake vs 35.0%). Red meat, poultry, fish and yogurt contributed more to animal protein intake whereas processed meat and cheese contributed less when compared to the first tertile (Supplementary Table S5). Regarding plant protein intake, refined grains had a lower contribution in the third tertile compared to the first (47.3% vs 60.7%) and other plant-based families made greater contributions which resulted in more plant protein diversity, expressed as BI-PBF (0.64 vs 0.55), with a better contribution of different plant protein sources (Fig. 1a).

Fig. 1 Contribution of plant-based food families to plant protein intake, expressed as the percentage of plant protein intake, and plant protein diversity, expressed as the Berry-Index – Plant-based families (BI-PBF) across tertiles of the proportion of total energy intake from a. unprocessed/minimally processed foods (MPF), b. processed foods (PF) and c. ultra-processed foods (UPF) in the French adult population INCA3 (n=1774) (Values are means adjusted for the season of recall; * indicates significantly different from the first tertile)

Total animal protein intake did not change across the tertiles of PFp. However, cheese and processed meat contributed more to animal protein intake whereas milk, eggs and yoghurt contributed less in the third vs the first tertile. Plant protein intake was higher in the third compared to the first tertile of PFp (29.0 g/day vs 23.7 g/day) and so was the proportion of plant protein in the diet (35.7% of total protein intake vs 31.7%) (Supplementary Table S5). The contribution of refined grains to plant protein intake was higher in the third than in the first tertile (62.2% vs 48.8%) resulting in less plant protein diversity (BI-PBF of 0.53 vs 0.64). Therefore, plant protein intake was less evenly distributed among plant protein sources in the third than in the first tertile of PFp (Fig. 1b).

Plant protein intake was lower in the third tertile of UPFp than in the first tertile (24.1 g/day vs 28.4 g/day and 32.3% of total protein intake vs 35.3%). Animal protein intake did not differ significantly across the UPFp tertiles, but when comparing the third tertile with the first, processed meat and milk contributed more to animal protein intake while poultry, fish and cheese contributed less (Supplementary Table S5). Plant protein diversity did not change significantly across the tertiles (Fig. 1c).

Degree of processing and food group consumption

As for protein intakes, mean intakes of food groups differed between the third tertiles of the proportion of MPF, PF and UPF in the diet (Supplementary Figure S3). Compared to the general population, participants in the highest tertile of MPFp consumed more plant foods that are usually minimally processed such as soups (+53%), nuts and oilseeds (+50%), and fruits (+36%), animal foods that are usually minimally processed such as fish (+37%), poultry (+32%) or milk (+31%) and less processed meat (-39%), savory pastries (-52%) and alcoholic beverages (-37%). Participants in the highest tertile of PFp consumed more refined bread (+67%), alcoholic beverages (+51%), cheeses (+40%) and processed meats (+15%) and less breakfast cereals (-63%) and sweet beverages (-48%) compared to the general population. Finally, participants in the highest tertile of UPFp consumed less minimally processed plant or animal foods, and more processed meats (+23%), sweet beverages (+70%), breakfast cereals (+63%), savory pastries (+59%), confectionery and chocolate (+39%) and fruit juices (+34%).

Associations between food processing and diet quality, and related to protein intakes

The PANDiet score and its sub-scores (adequacy sub-score, AS and moderation sub-score, MS) increased with the proportion of MPF and to a lesser extent with the proportion of PF, whereas they decreased in the higher tertile of UPFp. Similarly, the PDI and hPDI scores increased with the proportion of MPF and decreased with the proportion of UPF. The opposite trend was observed for the uPDI score (Fig. 2 and Supplementary Table S6).

Fig. 2 Diet quality indices across tertiles of the proportion of total energy intake from respectively unprocessed/minimally processed foods (MPFp), processed foods (PFp) and ultra-processed foods (UPFp) in the French adult population INCA3 (n=1774). a, b and c respectively, PANDiet score, Adequacy sub-score (AS) and Moderation sub-score (MS). d, e and f respectively, Plant-based diet (PDI), Healthy plant-based diet (hPDI) and Unhealthy plant-based diet (uPDI) scores (values are means ± SEM adjusted for the season of recall; * indicates significantly different from the first tertile)

In a model using mutually adjusted NOVA categories and representing substitutions for MPFp, PANDiet was negatively associated with increases of PFp (β=-0.11) and UPFp (β=-0.16), while uPDI was positively associated with PFp (β=0.12) and UPFp (β=0.13) and hPDI was negatively associated with UPFp (β=-0.05) but not with PFp (Table 1).

Associations with PANDiet, hPDI and uPDI were then evaluated independently with respect to MPFp, PFp and UPFp variables (Table 2). The PANDiet score was positively associated with MPFp (β=0.14), and the association was attenuated when controlling for protein intake and/or plant protein diversity (BI-PBF). PANDiet was not associated with PFp but was associated when controlling for BI-PBF (β=0.05) and negatively associated when controlling for protein intake (β=-0.08) and when controlling for protein intake and BI-PBF (β=-0.04). PANDiet was negatively associated with UPFp (β=-0.05) in all models except when controlling only for protein intake. hPDI was positively associated with MPFp (β=0.04) unless controlling for BI-PBF, but not associated with PFp (unless controlling for BI-PBF (β=0.11) or for protein (β=-0.03)), and negatively associated with UPFp (β=-0.07) in all models. uPDI was negatively associated with MPFp (β=-0.13) in all models but the association was attenuated when controlling for protein intake and BI-PBF, and positively associated with PFp (β=0.04), unless when controlling for BI-PBF (β=-0.07), and UPFp (β=0.06) in all models.

Furthermore, the association between the degree of food processing and its impact on health outcomes was estimated according to the dietary patterns computed from the proportion of total energy intake from MPF, PF and UPF taken separately, using the EpiDiet model. Our simulation revealed that diets containing a higher proportion of MPF could be more beneficial to health (Fig. 3). Compared to the figures of death observed in the French population in 2014 (9,709 deaths from cerebrovascular diseases, 13,020 from ischemic heart diseases and 3,597 from diabetes), consumption of a diet with higher MPFp (consumption pattern of the 3rd tertile of MPFp compared to the 1st tertile) could potentially decrease the number of deaths from cerebrovascular diseases by 25% [23-27%, 95% uncertainty interval] with 2419 deaths being avoided, from ischemic heart diseases by 31% [29-33%, 95%UI] with 4023 deaths being avoided, and from diabetes by 19% [16-21%, 95%UI] with 665 deaths being avoided. Meanwhile, higher share of UPFp in the diet (consumption pattern of the 3rd tertile of UPFp compared to the 1st tertile) could increase deaths from metabolic diseases: the theoretical percentage of deaths added was 19% [16-22%, 95%UI] for cerebrovascular diseases (+1880 deaths), 42% [11-73%, 95%UI] for ischemic heart diseases (+5448 deaths) and 30% [-3-63%, 95%UI] for diabetes (+1066 deaths). The same numbers for dietary patterns computed from PFp were 20% [18-22%, 95%UI] for cerebrovascular diseases (+1911 deaths), 11% [6-16%, 95%UI] for ischemic heart diseases (+1419 deaths), and 16% [5-26%, 95%UI] for diabetes (+560 deaths). For the estimation of the avoided death with higher MPF consumption, main explaining factors of the model were the higher consumption of fruits and vegetables and the lower consumption of processed meats. For the estimation of the excess death with higher PF consumption, main explaining factors of the model were the lower consumption of nuts and seeds, the higher consumption of sodium and a higher energy intake, whereas for excess death with higher UPF consumption, main explaining factors of the model were the lower consumption of vegetables and the higher consumption of processed meats and sugar-sweetened beverages (Supplementary Table S7).

Fig. 3 Estimation of potentially avoided or added cardiometabolic deaths (± 95% CI) when shifting from first to third tertile of MPFp (proportion of total energy intake from unprocessed/minimally processed foods), PFp (proportion of total energy intake from processed foods) and UPFp (proportion of total energy intake from ultra-processed food, as predicted by the EpiDiet (Evaluate the Potential Impact of a Diet), compared to the number of deaths of the French adult population (the percentage corresponds to the percentage of death added (if positive) or avoided (if negative))

Discussion

This study has shown that consumption of MPF was associated with total and animal protein intakes and diet quality; consumption of PF was associated with under-diversified plant protein intake and inversely with diet quality; and consumption of UPF was inversely associated with total protein intake and diet quality. Most associations between the degree of food processing and diet quality were attenuated when adjusting for total protein intake and plant protein diversity.

The sociodemographic characteristics of people consuming high proportions of MPF and PF in their diet had many similarities and both appeared to contrast with those of individuals eating a high proportion of UPF. Similar sociodemographic profiles for high consumers of MPF had been found in a study in the UK, where women and older people had a higher percentage of energy intake from MPF [51]. The fact that younger adults and people in lower socioeconomic groups consume more UPF has been reported in previous studies [52–54]. This can be taken as an illustration of the continuing shift from traditional diets towards a western diet that is rendered uniform by ultra-processed foods [55].

The degree of food processing was associated with the plant/animal protein pattern. A higher consumption of MPF meant higher intakes of total protein mostly as animal protein. This could be expected inasmuch as the main food groups contributing to animal-based proteins are classified as unprocessed/minimally processed foods such as poultry, red meat, fish, yogurt and milk. With a higher PF consumption, intakes of plant protein were higher, and this could be almost fully ascribed to a much higher intake of bread, under a general pattern that may be referred to as traditional [56, 57]. Indeed, in high PF consumers, 62% of plant protein came from refined grains, which explains why a higher consumption of processed foods was associated with a poorer plant protein diversity, in contrast with high consumers of MPF who had a more diverse plant protein intake. High consumers of UPF had lower protein intakes, as reported in previous studies [51, 58, 59], this could be ascribed to a lower consumption of protein food groups and higher intake of more miscellaneous food groups low in protein such as sweet beverages, pastries or confectionery.

This study provides a fairly comprehensive view of the relationship between the degree of food processing and diet quality. Higher consumers of MPF had greater nutrient adequacy, higher healthful PDI, lower unhealthful PDI, and a lower predicted risk of death from cardiometabolic diseases, whereas the opposite applied among higher consumers of UPF. The results using substitution models clearly showed that substituting MPF by PF or UPF had a detrimental effect on diet quality.

In another French population, poorer compliance with dietary guidelines was found in the highest quartile of ultra-processed food consumers [52]. This association had also been found in the US population where overall dietary quality was measured using a nutrient balanced-pattern PCA-derived factor score [59]. The consumption of UPF has been associated with excessive sugar intake [60] and with lower intakes of vitamins and minerals [58], although this might depend on the level of usage of fortification in the food industry. Regarding long-term health effects of consumption of UPF, our assessment of changes in mortality rates from cardiovascular diseases are in line with findings in the literature, inasmuch as a higher consumption of ultra-processed foods has been associated with a higher risk of all-cause mortality of 31% in the USA [25] and 44% in Spain [24]. Among UK adults, a higher consumption of UPF has also been associated with a higher risk of obesity

[61]. While the literature regarding UPF consumption has been growing, characterizing diet quality and the health impact of consuming MPF have been overlooked and the data are scarce [51]. However, it should be noted that a high consumption of MPF is ubiquitous in traditional reference diets such as the Mediterranean diet which has proven health benefits [62].

In our study, using comparative risk assessment on the diets, we estimated higher deaths from cardiovascular diseases with higher consumption of UPF or PF, and lower deaths with higher consumption of MPF. We were able to identify nutritional factors that contributed to estimates of avoided or added death. Differences in BMI and energy intake were important factors for high consumers of MPF and PF, although less than nutritional factors, but they were more secondary for high consumers of UPF. Estimations of deaths from high consumption of UPF are therefore poorly attributable to energy intake and BMI but to other nutritional factors. High consumers of MPF have a dietary pattern that is known to be associated with lower risk of cardiovascular diseases (fruits, vegetables, nuts, but also fish and dairy) whereas high consumers of PF and UPF consumed more food groups known to be associated with higher risk of cardiovascular diseases (refined grains, products rich in sodium, alcohol, sugar-sweetened beverages, etc.) [63, 64]. Furthermore, adherence to overall plant-based diet index (PDI) have been associated with a lower risk of cardiovascular disease, cardiovascular disease mortality and all-cause mortality [65], which is consistent with our findings since PDI only increased with higher share of MPF, where lower estimates of death from cardiovascular diseases were observed. Using modelling analysis to predict the impact of sustainable diets strategies on health, a study found that adopting diets that are more plant-based would decrease mortality up to 12% [66]. The methodological framework used in this study was similar to the Epidiet model that we used, although we included more nutritional factors (24 instead of 9) and only focused on mortality from three diseases.

Beyond showing the association between the degree of processing of the foods consumed and diet quality, the major new finding of this study was that the specific profiles of protein consumption associated with these patterns are an important determinant of the relationship with diet quality. In particular, the association between the proportion of MPF and most diet quality criteria were attenuated when adjusting for protein intake and plant protein diversity. Likewise, the relationships between the proportions of PF and UPF and nutrient adequacy were attenuated or inversed when adjusting for protein intake and plant protein diversity.

Indeed, protein intake is an important determinant of diet quality and this is closely dependent on the type of protein food consumed [13, 56, 67]. Plant protein intake and plant-based diets are generally considered as healthy but there are some unhealthful versions of plant-based diets [15, 16]. This may explain why in our study the consumption of processed foods was associated with lower dietary quality even though it is accompanied by a higher intake of plant protein. Plant protein consumed in high consumers of processed foods, mostly refined grains, may not be an important contributor to diet quality, compared to other sources such as legumes, nuts and seeds, and plant protein diversity appears as a condition for a beneficial effect of plant protein, confirming our earlier report [33].

We believe that our present findings lend further credence to this viewpoint by showing that the relationship between patterns of food processing and diet quality are in part linked to the pattern of plant/animal protein intake. People with a high consumption of MPF have a higher animal protein intake but this comes from raw sources, and they have a better diversity of plant protein intake, all of which explain better diet quality. People with a high consumption of PF would have a better diet quality if the increase in plant protein intake were not at the expense of its diversity [33]. People with a high consumption of UPF have a lower intake of protein foods, a lower plant:animal protein intake and are reliant on diverse ultra-processed foods which taken together have a detrimental effect on their diet quality.

More and more consumers are prone to shift towards a more plant-based diet [68, 69], but this occurs in the context of a food offer that is increasingly dominated by processed and ultra-processed foods which exert an adverse effect on diet quality. This plant-based shift may contribute to improving some aspects of sustainability such as the environmental impact of the diet, but the final impact on its quality and on health outcomes will depend to a great extent on the composition of the plant-based foods and overall diet consumed. Our study has highlighted two possible better pathways, which consist in either increasing the consumption of MPF, preferably with a higher plant protein intake, or choosing processed foods that contribute to an increase in the proportion of plant proteins while maintaining plant protein diversity and enabling the favorable nutrient package traditionally associated with plant proteins.

Limitations of the study

One limitation of this study may concern our use of the NOVA classification, where the ultra-processed foods group is very broad and includes markedly differing foods that have been ascribed to this group for different reasons (presence of additives or highly technological food processing). Some food items are also classified according to their method of preparation, requiring imputations that could be questionable (i.e. systematically considering foods from fast-food restaurant as industrially processed). However, the NOVA classification has been largely employed in the literature and its use offers a clear reference when discussing our results. Another limitation concerns our food composition database. Indeed, a food item with the same overall label was assigned to different NOVA categories depending on its origin despite there being a lack of data regarding its composition. Regarding the study size and generalizability, the present study took advantage of a representative setting in a country with western dietary patterns and an important share of industrial foods, with a diversity of patterns. High consumers of MPF and UPF appear to have dietary patterns comparable to those reported in studies using other samples. High consumers of PF, which represent a more traditional pattern might be less generalizable, but data are lacking for further analysis since this NOVA category has been much less studied. Lastly, although the data came from the latest French national representative survey (in 2014-2015), they may not have been sufficiently recent to reflect current dietary transitions and the increased use of plant-based products.

Conclusion

Although the consumption of UPF has been widely studied in recent years, to our knowledge very few studies have investigated the associations between the consumption of MPF, PF and diet quality. Using a variety of indices, we found that the consumption of MPF was associated with higher diet quality whereas the opposite trend was found with consumption of UPF. We also show that protein consumption patterns differed according to the degree of food processing, and that it explains part of the associations with diet quality. Higher consumers of MPF had a higher protein intake, with a lower plant:animal protein ratio, but they had a healthier plant-based protein intake and a fully favorable dietary pattern. Higher consumers of PF had higher plant protein intakes but lower plant protein diversity, and a greater risk of cardiometabolic death. Higher consumers of UPF had a lower protein intake and poor diet quality on all dimensions, including a markedly higher cardiometabolic risk. We can thus conclude that healthy plant protein patterns are crucial to a future shift in protein intake in the context of a food system that is increasingly dominated by ultra-processed foods.

References

1. Monteiro CA, Cannon G, Levy R, et al (2016) NOVA. The star shines bright. [Food classification Puclib health] World Nutrition 7:28–38

2. Monteiro CA, Cannon G, Levy RB, et al (2019) Ultra-processed foods: what they are and how to identify them. Public Health Nutr 22:936–941. https://doi.org/10.1017/S1368980018003762

3. Martínez Steele E, Baraldi LG, Louzada ML da C, et al (2016) Ultra-processed foods and added sugars in the US diet: evidence from a nationally representative cross-sectional study. BMJ Open 6:e009892. https://doi.org/10.1136/bmjopen-2015-009892

4. Rauber F, da Costa Louzada ML, Steele E, et al (2018) Ultra-Processed Food Consumption and Chronic Non-Communicable Diseases-Related Dietary Nutrient Profile in the UK (2008–2014). Nutrients 10:587. https://doi.org/10.3390/nu10050587

5. Monteiro CA, Moubarac J-C, Cannon G, et al (2013) Ultra-processed products are becoming dominant in the global food system: Ultra-processed products: global dominance. Obes Rev 14:21–28. https://doi.org/10.1111/obr.12107

6. Monteiro CA, Cannon G, Moubarac J-C, et al (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr 21:5–17. https://doi.org/10.1017/S1368980017000234

7. Martínez Steele E, Raubenheimer D, Simpson SJ, et al (2018) Ultra-processed foods, protein leverage and energy intake in the USA. Public Health Nutr 21:114–124. https://doi.org/10.1017/S1368980017001574

8. Gerber PJ, Food and Agriculture Organization of the United Nations (2013) Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations, Rome

9. Wu G, Fanzo J, Miller DD, et al (2014) Production and supply of high-quality food protein for human consumption: sustainability, challenges, and innovations: Sustainability, challenge and innovations. Ann NY Acad Sci 1321:1–19. https://doi.org/10.1111/nyas.12500

10. Springmann M, Clark M, Mason-D'Croz D, et al (2018) Options for keeping the food system within environmental limits. Nature 562:519–525. https://doi.org/10.1038/s41586-018-0594-0

11. Willett W, Rockström J, Loken B, et al (2019) Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet 393:447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

12. World Cancer Research Fund, American Institute for Cancer Research. (2018) Diet, nutrition, physical activity and cancer: a global perspective. The third Expert Report

13. Mariotti F (2019) Animal and Plant Protein Sources and Cardiometabolic Health. Adv Nutr 10:S351–S366. https://doi.org/10.1093/advances/nmy110

14. Song M, Fung TT, Hu FB, et al (2016) Association of Animal and Plant Protein Intake With All-Cause and Cause-Specific Mortality. JAMA Intern Med 176:1453. https://doi.org/10.1001/jamainternmed.2016.4182

15. Satija A, Bhupathiraju SN, Spiegelman D, et al (2017) Healthful and Unhealthful Plant-Based Diets and the Risk of Coronary Heart Disease in U.S. Adults. J Am Coll Cardiol 70:411–422. https://doi.org/10.1016/j.jacc.2017.05.047

16. Satija A, Bhupathiraju SN, Rimm EB, et al (2016) Plant-Based Dietary Patterns and Incidence of Type 2 Diabetes in US Men and Women: Results from Three Prospective Cohort Studies. PLoS Med 13:e1002039. https://doi.org/10.1371/journal.pmed.1002039

17. Gehring J, Touvier M, Baudry J, et al (2020) Consumption of Ultra-Processed Foods by Pesco-Vegetarians, Vegetarians, and Vegans: Associations with Duration and Age at Diet Initiation. J Nutr nxaa196. https://doi.org/10.1093/jn/nxaa196

18. Moodie R, Stuckler D, Monteiro C, et al (2013) Profits and pandemics: prevention of harmful effects of tobacco, alcohol, and ultra-processed food and drink industries. The Lancet 381:670–679. https://doi.org/10.1016/S0140-6736(12)62089-3

19. Vandevijvere S, Jaacks LM, Monteiro CA, et al (2019) Global trends in ultraprocessed food and drink product sales and their association with adult body mass index trajectories. Obesity Reviews 20:10–19. https://doi.org/10.1111/obr.12860

20. Monteiro CA, Cannon G, Lawrence M, et al (2019) Ultra-processed foods, diet quality, and health using the NOVA classification system. FAO, Rome

21. Fiolet T, Srour B, Sellem L, et al (2018) Consumption of ultra-processed foods and cancer risk: results from NutriNet-Santé prospective cohort. BMJ k322. https://doi.org/10.1136/bmj.k322

22. Mendonça R de D, Lopes ACS, Pimenta AM, et al (2016) Ultra-Processed Food Consumption and the Incidence of Hypertension in a Mediterranean Cohort: The Seguimiento Universidad de Navarra Project. AJHYPE hpw137. https://doi.org/10.1093/ajh/hpw137

23. Nardocci M, Leclerc B-S, Louzada M-L, et al (2019) Consumption of ultra-processed foods and obesity in Canada. Can J Public Health 110:4–14. https://doi.org/10.17269/s41997-018-0130-x

24. Blanco-Rojo R, Sandoval-Insausti H, López-Garcia E, et al (2019) Consumption of Ultra-Processed Foods and Mortality: A National Prospective Cohort in Spain. Mayo Clinic Proceedings 94:2178–2188. https://doi.org/10.1016/j.mayocp.2019.03.035

25. Kim H, Hu EA, Rebholz CM (2019) Ultra-processed food intake and mortality in the USA: results from the Third National Health and Nutrition Examination Survey (NHANES III, 1988–1994). Public Health Nutr 22:1777–1785. https://doi.org/10.1017/S1368980018003890

26. Hall KD, Ayuketah A, Brychta R, et al (2019) Ultra-Processed Diets Cause Excess Calorie Intake and Weight Gain: An Inpatient Randomized Controlled Trial of Ad Libitum Food Intake. Cell Metabolism 30:67-77.e3. https://doi.org/10.1016/j.cmet.2019.05.008

27. (2017) Opinion of the French Agency for Food, Environmental and Occupational Health & Safety on “the Third Individual and National Survey on Food Consumption (INCA3 Survey).” French Agency for Food, Environmental and Occupational Health Safety (Anses).

28. Dubuisson C, Dufour A, Carrillo S, et al (2019) The Third French Individual and National Food Consumption (INCA3) Survey 2014–2015: method, design and participation rate

in the framework of a European harmonization process. Public Health Nutr 22:584–600. https://doi.org/10.1017/S1368980018002896

29. Henry C (2005) Basal metabolic rate studies in humans: measurement and development of new equations. Public Health Nutr 8:1133–1152. https://doi.org/10.1079/PHN2005801

30. Black A (2000) Critical evaluation of energy intake using the Goldberg cut-off for energy intake:basal metabolic rate. A practical guide to its calculation, use and limitations. Int J Obes 24:1119–1130. https://doi.org/10.1038/sj.ijo.0801376

31. Slimani N, Freisling H, Huybrechts I, et al (2013) Food Consumption Data Collection Methodology for the EU Menu Survey (EMP-PANEU) Final Report. EFSA supporting publication

32. French Agency for Food, Environmental and Occupational Health & Safety (2016) ANSES-CIQUAL French food composition table version 2016

33. Salomé M, de Gavelle E, Dufour A, et al (2019) Plant-Protein Diversity Is Critical to Ensuring the Nutritional Adequacy of Diets When Replacing Animal With Plant Protein: Observed and Modeled Diets of French Adults (INCA3). J Nutr nxz252. https://doi.org/10.1093/jn/nxz252

34. Drescher LS, Thiele S, Mensink GBM (2007) A New Index to Measure Healthy Food Diversity Better Reflects a Healthy Diet Than Traditional Measures. The Journal of Nutrition 137:647–651. https://doi.org/10.1093/jn/137.3.647

35. de Oliveira Otto MC, Padhye NS, Bertoni AG, et al (2015) Everything in Moderation - Dietary Diversity and Quality, Central Obesity and Risk of Diabetes. PLoS ONE 10:e0141341. https://doi.org/10.1371/journal.pone.0141341

36. Verger EO, Mariotti F, Holmes BA, et al (2012) Evaluation of a Diet Quality Index Based on the Probability of Adequate Nutrient Intake (PANDiet) Using National French and US Dietary Surveys. PLoS ONE 7:e42155. https://doi.org/10.1371/journal.pone.0042155

37. de Gavelle E, Huneau J-F, Fouillet H, Mariotti F (2019) The Initial Dietary Pattern Should Be Considered when Changing Protein Food Portion Sizes to Increase Nutrient Adequacy in French Adults. The Journal of Nutrition 149:488–496. https://doi.org/10.1093/jn/nxy275

38. Anses (2016) Actualisation des repères du PNNS : élaboration des références nutritionnelles. French Agency for Food, Environmental and Occupational Health Safety (Anses)., Maisons-Alfort, France

39. Anses (2019) Anses Opinion on the updating of the PNNS dietary guidelines for women from menopause and men over 65 years of age. French Agency for Food, Environmental and Occupational Health Safety (Anses)., Maisons-Alfort, France

40. Murray CJL, Lopez AD (2013) Measuring the Global Burden of Disease. N Engl J Med 369:448–457. https://doi.org/10.1056/NEJMra1201534

41. Kesse-Guyot E, Chaltiel D, Wang J, et al (2020) Sustainability analysis of French dietary guidelines using multiple criteria. Nat Sustain 3:377–385. https://doi.org/10.1038/s41893-020-0495-8

42. Aune D, Giovannucci E, Boffetta P, et al (2017) Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality—a systematic review and dose-response meta-analysis of prospective studies. International Journal of Epidemiology 46:1029–1056. https://doi.org/10.1093/ije/dyw319

43. Micha R, Peñalvo JL, Cudhea F, et al (2017) Association Between Dietary Factors and Mortality From Heart Disease, Stroke, and Type 2 Diabetes in the United States. JAMA 317:912. https://doi.org/10.1001/jama.2017.0947

44. Scarborough P, Harrington RA, Mizdrak A, et al (2014) The Preventable Risk Integrated ModEl and Its Use to Estimate the Health Impact of Public Health Policy Scenarios. Scientifica 2014:1–21. https://doi.org/10.1155/2014/748750

45. Inserm CépiDC Classification internationale des maladies (CIM). In: CépiDC Internet. https://www.cepidc.inserm.fr/causes-medicales-de-deces/classification-internationale-des-maladies-cim. Accessed 26 Feb 2019

46. Insee Évolution et structure de la population en 2014. In: Insee Internet. https://www.insee.fr/fr/statistiques/2862200. Accessed 26 Feb 2019

47. CépiDc (2019) Causes Médicales des Décès en 2014. https://www.cepidc.inserm.fr/causes-medicales-de-deces/interroger-les-donnees-de-mortalite . Accessed 26 Feb 2019

48. Thiébaut A, Kesse E, Com-Nougué C, et al (2004) Ajustement sur l'apport énergétique dans l'évaluation des facteurs de risque alimentaires. Revue d'Épidémiologie et de Santé Publique 52:539–557. https://doi.org/10.1016/S0398-7620(04)99093-1

49. Willett WC, Howe GR, Kushi LH (1997) Adjustment for total energy intake in epidemiologic studies. The American Journal of Clinical Nutrition 65:1220S-1228S. https://doi.org/10.1093/ajcn/65.4.1220S

50. Saltelli A, Ratto M, Andres T, et al (2008) Global Sensitivity Analysis: The Primer. John Wiley & Sons, Chichester

51. Adams J, White M (2015) Characterisation of UK diets according to degree of food processing and associations with socio-demographics and obesity: cross-sectional analysis of UK National Diet and Nutrition Survey (2008–12). Int J Behav Nutr Phys Act 12:160. https://doi.org/10.1186/s12966-015-0317-y

52. Julia C, Martinez L, Allès B, et al (2018) Contribution of ultra-processed foods in the diet of adults from the French NutriNet-Santé study. Public Health Nutr 21:27–37. https://doi.org/10.1017/S1368980017001367

53. Baraldi LG, Martinez Steele E, Canella DS, Monteiro CA (2018) Consumption of ultra-processed foods and associated sociodemographic factors in the USA between 2007 and 2012: evidence from a nationally representative cross-sectional study. BMJ Open 8:e020574. https://doi.org/10.1136/bmjopen-2017-020574

54. Machado PP, Steele EM, Louzada ML da C, et al (2019) Ultra-processed food consumption drives excessive free sugar intake among all age groups in Australia. Eur J Nutr. https://doi.org/10.1007/s00394-019-02125-y

55. Baker P, Machado P, Santos T, et al (2020) Ultra-processed foods and the nutrition transition: Global, regional and national trends, food systems transformations and political economy drivers. Obesity Reviews 21:. https://doi.org/10.1111/obr.13126

56. de Gavelle E, Huneau J-F, Mariotti F (2018) Patterns of Protein Food Intake Are Associated with Nutrient Adequacy in the General French Adult Population. Nutrients 10:226. https://doi.org/10.3390/nu10020226

57. Gazan R, Béchaux C, Crépet A, et al (2016) Dietary patterns in the French adult population: a study from the second French national cross-sectional dietary survey (INCA2) (2006–2007). Br J Nutr 116:300–315. https://doi.org/10.1017/S0007114516001549

58. Louzada ML da C, Ricardo CZ, Steele EM, et al (2018) The share of ultra-processed foods determines the overall nutritional quality of diets in Brazil. Public Health Nutr 21:94–102. https://doi.org/10.1017/S1368980017001434

59. Martínez Steele E, Popkin BM, Swinburn B, Monteiro CA (2017) The share of ultra-processed foods and the overall nutritional quality of diets in the US: evidence from a nationally representative cross-sectional study. Popul Health Metrics 15:6. https://doi.org/10.1186/s12963-017-0119-3

60. Rauber F, Louzada ML da C, Martinez Steele E, et al (2019) Ultra-processed foods and excessive free sugar intake in the UK: a nationally representative cross-sectional study. BMJ Open 9:e027546. https://doi.org/10.1136/bmjopen-2018-027546

61. Rauber F, Chang K, Vamos EP, et al (2020) Ultra-processed food consumption and risk of obesity: a prospective cohort study of UK Biobank. Eur J Nutr. https://doi.org/10.1007/s00394-020-02367-1

62. Salas-Salvadó J, Becerra-Tomás N, García-Gavilán JF, et al (2018) Mediterranean Diet and Cardiovascular Disease Prevention: What Do We Know? Prog Cardiovasc Dis 61:62–67. https://doi.org/10.1016/j.pcad.2018.04.006

63. Anand SS (2015) Food Consumption and its Impact on Cardiovascular Disease: Importance of Solutions Focused on the Globalized Food System: A Report From the Workshop Convened by the World Heart Federation. Cardiovascular Disease 66:25

64. Petersen KS, Flock MR, Richter CK, et al (2017) Healthy Dietary Patterns for Preventing Cardiometabolic Disease: The Role of Plant-Based Foods and Animal Products. Curr Dev Nutr 1:cdn.117.001289. https://doi.org/10.3945/cdn.117.001289

65. Kim H, Caulfield LE, Garcia-Larsen V, et al (2019) Plant-Based Diets Are Associated With a Lower Risk of Incident Cardiovascular Disease, Cardiovascular Disease Mortality, and All-Cause Mortality in a General Population of Middle-Aged Adults. JAHA 8:. https://doi.org/10.1161/JAHA.119.012865

66. Springmann M, Wiebe K, Mason-D'Croz D, et al (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. The Lancet Planetary Health 2:e451–e461. https://doi.org/10.1016/S2542-5196(18)30206-7

67. Tian S, Xu Q, Jiang R, et al (2017) Dietary Protein Consumption and the Risk of Type 2 Diabetes: A Systematic Review and Meta-Analysis of Cohort Studies. Nutrients 9:982. https://doi.org/10.3390/nu9090982

68. Sanchez-Sabate R, Badilla-Briones Y, Sabaté J (2019) Understanding Attitudes towards Reducing Meat Consumption for Environmental Reasons. A Qualitative Synthesis Review. Sustainability 11:6295. https://doi.org/10.3390/su11226295

69. Malek L, Umberger WJ, Goddard E (2019) Committed vs. uncommitted meat eaters: Understanding willingness to change protein consumption. Appetite 138:115–126. https://doi.org/10.1016/j.appet.2019.03.024

Table 1 Estimated effect of substituting unprocessed/minimally processed foods (MPF) with processed culinary ingredients, processed foods (PF) or ultra-processed foods (UPF) on the PANDiet, hPDI and uPDI diet quality scores under a mutually adjusted multivariate substitution model[a].

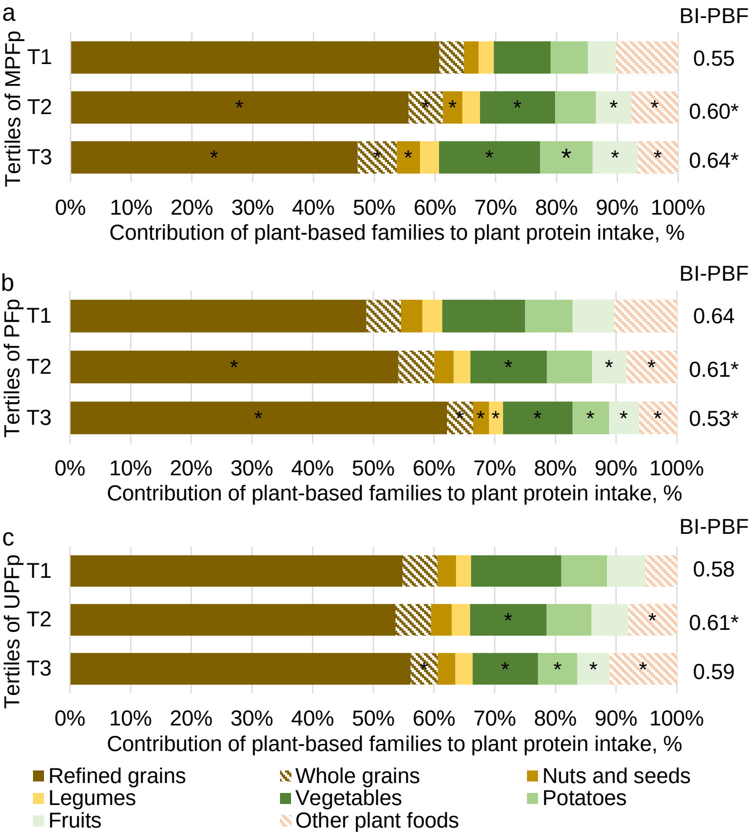
	PANDiet		hPDI		uPDI	
	β (95% CI)	*P*	β (95% CI)	*P*	β (95% CI)	*P*
Proportion of total energy intake from PF[b]	-0.11 (-0.14, -0.09)	<0.001	0.00 (-0.03, 0.03)	0.871	0.12 (0.09, 0.16)	<0.001
Proportion of total energy intake from UPF[b]	-0.16 (-0.19, -0.14)	<0.001	-0.05 (-0.08, -0.03)	<0.001	0.13 (0.10, 0.16)	<0.001

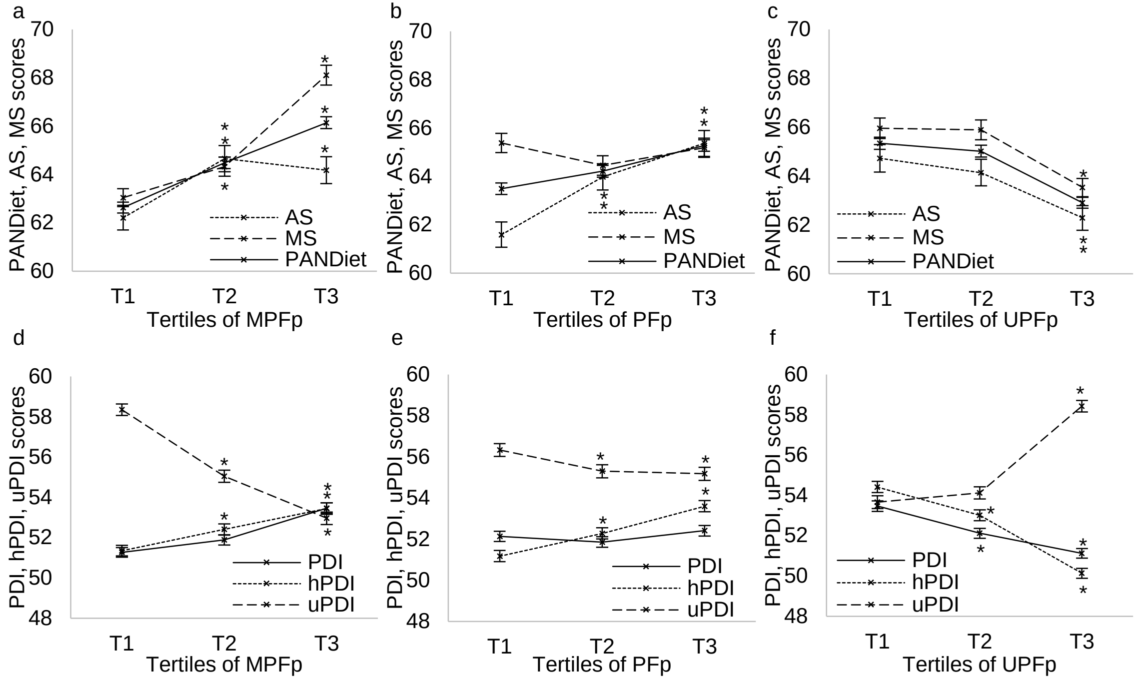
[a] Data from the Individual and National Study on Food Consumption Survey 3, n=1774. Values are regression coefficients (95% CIs) estimated with multiple linear regressions. Data were collected by three 24h recalls.
[b] Model where the proportion of processed culinary ingredients, PF and UPF in the diet were included for mutual adjustment. The proportion of MPF was not included since it was taken as a reference for substitution. The model was adjusted for total energy intake, age, sex, educational level, occupational status, city size, perception of financial status, season of record, region of France and matrimonial status. The association with the proportion of processed culinary ingredients in the diet is not presented since it seems unlikely to substitute foods with culinary ingredients.
hPDI, healthy Plant-based Diet Index; NS, non-significant; PANDiet, Probability of Adequate Nutrient Intake in the Diet; PF, processed foods; uPDI, unhealthy Plant-based diet Index; UPF, ultra-processed foods.

Table 2 Associations between the PANDiet, hPDI and uPDI diet quality scores and variables of the NOVA classification (proportion of total energy intake from unprocessed/minimally processed foods (MPF), processed foods (PF) and ultra-processed foods (UPF)) using multivariate models adjusted for the characteristics of protein intake, in the French adult population[a].

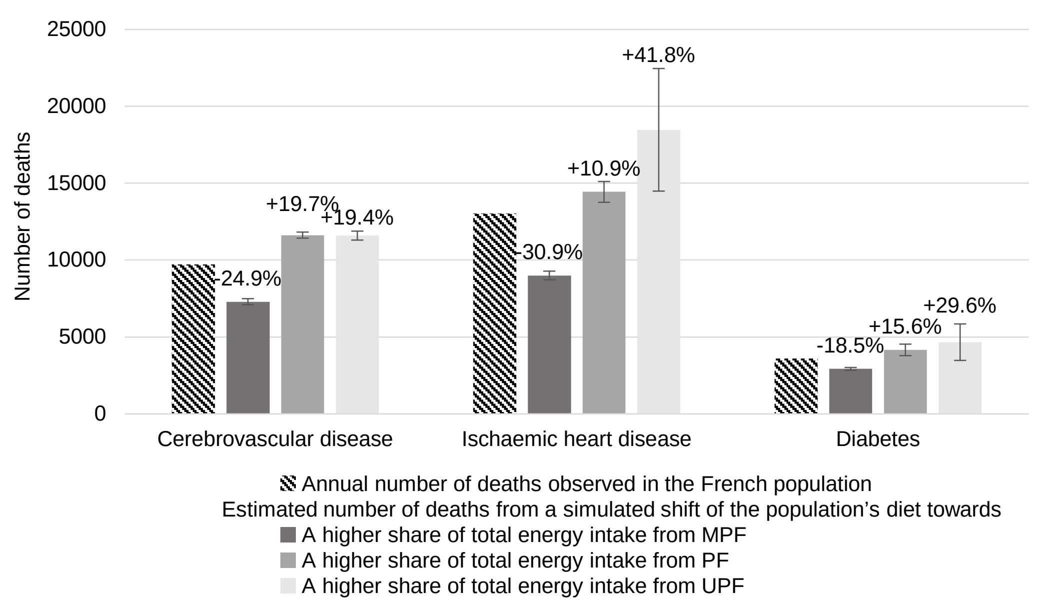
	PANDiet		hPDI		uPDI	
	β (95% CI)	*P*	β (95% CI)	*P*	β (95% CI)	*P*
Proportion of total energy intake from MPF						
Basic model[b]	0.14 (0.12, 0.16)	<0.001	0.04 (0.01, 0.06)	0.003	-0.13 (-0.15, -0.10)	<0.001
Controlling for protein intake[c]	0.10 (0.08, 0.12)	<0.001	0.06 (0.03, 0.08)	<0.001	-0.10 (-0.13, -0.07)	<0.001
Controlling for BI-PBF[d]	0.12 (0.10, 0.14)	<0.001	0.00 (-0.03, 0.02)	0.850	-0.07 (-0.10, -0.04)	<0.001
Controlling for protein intake + BI-PBF[e]	0.07 (0.05, 0.09)	<0.001	0.00 (-0.02, 0.03)	0.771	-0.04 (-0.06, -0.01)	0.004
Proportion of total energy intake from PF						
Basic model[b]	0.02 (-0.02, 0.02)	0.965	0.02 (0.00, 0.05)	0.084	0.04 (0.02, 0.07)	0.002
Controlling for protein intake[c]	-0.08 (-0.11, -0.06)	<0.001	-0.03 (-0.05, 0.00)	0.045	0.06 (0.04, 0.09)	<0.001
Controlling for BI-PBF[d]	0.05 (0.03, 0.08)	<0.001	0.11 (0.08, 0.13)	<0.001	-0.07 (-0.10, -0.04)	<0.001
Controlling for protein intake + BI-PBF[e]	-0.04 (-0.06, -0.01)	0.002	0.06 (0.04, 0.09)	<0.001	-0.04 (-0.07, -0.01)	0.005
Proportion of total energy intake from UPF						
Basic model[b]	-0.05 (-0.07, -0.04)	<0.001	-0.07 (-0.09, -0.05)	<0.001	0.06 (0.04, 0.08)	<0.001
Controlling for protein intake[c]	-0.01 (-0.03, 0.00)	0.151	-0.05 (-0.07, -0.03)	<0.001	0.05 (0.03, 0.08)	<0.001
Controlling for BI-PBF[d]	-0.06 (-0.08, -0.05)	<0.001	-0.09 (-0.11, -0.07)	<0.001	0.08 (0.06, 0.10)	<0.001
Controlling for protein intake + BI-PBF[e]	-0.02 (-0.04, 0.00)	0.024	-0.06 (-0.08, -0.04)	<0.001	0.07 (0.05, 0.09)	<0.001

[a] Data from the Individual and National Study on Food Consumption Survey 3, n=1774. Values are regression coefficients (95% CIs) estimated with multiple linear regressions. Data were collected by three 24h recalls.
[b]Basic model adjusted for total energy intake, age, sex, educational level, occupational status, city size, perception of financial status, season of record, region of France and matrimonial status.
[c]Basic model further adjusted for animal protein and plant protein intakes, both being energy-adjusted using the residual method.
[d]Basic model further adjusted for plant protein diversity, evaluated with the BI-PBF score.
[e]Basic model further adjusted for animal protein and plant protein intakes and plant protein diversity (BI-PBF score).
BI-PBF, Berry-Index – Plant-based families; hPDI, healthy Plant-based Diet Index; MPF, unprocessed/minimally processed foods; NS, non-significant; PANDiet, Probability of Adequate Nutrient Intake; PF, processed foods; uPDI, unhealthy Plant-based diet Index; UPF, ultra-processed foods.


a
BI-PBF
Tertiles of MPFp
T1
T2
T3
0.55
0.60*
0.64*
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Contribution of plant-based families to plant protein intake, %
b
BI-PBF
Tertiles of PFp
T1
T2
T3
0.64
0.61*
0.53*
Contribution of plant-based families to plant protein intake, %
c
BI-PBF
Tertiles of UPFp
T1
T2
T3
0.58
0.61*
0.59
Contribution of plant-based families to plant protein intake, %
Refined grains
Whole grains
Nuts and seeds
Legumes
Vegetables
Potatoes
Fruits
Other plant foods



a
b
c
d
e
f
PANDiet, AS, MS scores
PDI, hPDI, uPDI scores
AS
MS
PANDiet
PDI
hPDI
uPDI
T1
T2
T3
Tertiles of MPFp
Tertiles of PFp
Tertiles of UPFp


25000
20000
15000
10000
5000
0
Number of deaths
+41.8%
+10.9%
+19.7%
+19.4%
-24.9%
-30.9%
+29.6%
+15.6%
-18.5%
Cerebrovascular disease
Ischaemic heart disease
Diabetes
Annual number of deaths observed in the French population
Estimated number of deaths from a simulated shift of the population's diet towards
A higher share of total energy intake from MPF
A higher share of total energy intake from PF
A higher share of total energy intake from UPF

European Journal of Nutrition

Contrary to ultra-processed foods, the consumption of unprocessed or minimally processed foods is associated with favorable patterns of protein intake, diet quality and lower cardiometabolic risk in French adults (INCA3).

Marion Salomé[1], Laura Arrazat[1], Juhui Wang[1], Ariane Dufour[2], Carine Dubuisson[2], Jean-Luc Volatier[2], Jean-François Huneau[1], François Mariotti[1]*

[1]Université Paris-Saclay, AgroParisTech, INRAE, UMR PNCA, 75005, Paris, France

[2]Risk Assessment Department, Methodology and Survey Unit, French Agency for Food, Environmental and Occupational Health & Safety (ANSES), 14 rue Pierre et Marie Curie, 94701 Maisons-Alfort Cedex, France

* Corresponding author: François Mariotti, 16 rue Claude Bernard, 75005 Paris, France, francois.mariotti@agroparistech.fr

Supplementary Table S1 Reference values of the PANDiet scoring system.

PANDiet score[1]

Average of Adequacy and Moderation subscores

Adequacy subscore			
Nutrient	**Reference value (/day)[2]**	**Variability**	**Source**
Protein	0.66 or 0.8 g/kg bw	12.5%	**[1]**
LA	3.08% EIEA	15%	**[3]**
ALA	0.769% EIEA	15%	**[3]**
DHA	0.192 g	15%	**[3]**
EPA + DHA	0.385 g	15%	**[3]**
Fiber	23 g	15%	**[2]**
Vitamin A	570 or 490 µg	15%	**[2]**
Thiamin	0.3 mg/1000 kcal	20%	**[4]**
Riboflavin	1.3 mg	15%	**[4]**
Niacin	5.44 mg NE/1000kcal	10%	**[2]**
Pantothenic acid	3.62 or 2.94 mg	30%	**[2]**
Vitamin B-6	1.5 or 1.3 mg	10%	**[5]**
Folate	250 µg	15%	**[2]**
Vitamin B-12	3.33 µg	10%	**[2]**
Vitamin C	90 mg	10%	**[2]**
Vitamin D	10 µg	25%	**[2]**
Vitamin E	5.8 or 5.5 mg	40%	**[2]**
Calcium	860 (<= 24 y.o) or 750 (>24 y.o.)	15% or 13%	**[2]**
Copper	1.0 or 0.8 mg	15%	**[2]**
Iodine	107 µg	20%	**[2]**
Bioavailable iron	See formula in de Gavelle et al. (7)		**[2]**
Magnesium	5 mg/kg bw	15%	**[2]**
Manganese	1.56 or 1.39 mg	40%	**[2]**
Phosphorus	Calcium (mmol) / 1.65 c.f. phosphorus section in de Gavelle et al. **[6]**	7.5% + CV Calcium (mg)	**[4]**
Potassium	2692 mg	15%	**[4]**
Selenium	54 µg	15%	**[2]**
Bioavailable zinc	0.642 + 0.038 b.w.	10%	**[2]**

Moderation subscore			
Nutrient	**Reference value (/day)**	**Variability**	**Source**
Protein	2.2 g/kg bw	12.5%	**[2]**
Total fat	44% EIEA	5%	**[2]**
SFA	12% EIEA	15%	**[2]**
Carbohydrates	60.5% EIEA	5%	**[2]**
Sugars (without lactose)	100 g	15%	**[2]**
Sodium	3482 or 2618 mg	40%	**[2]**

Tolerable Upper Intake Limits		**Source**
Vitamin A (retinol only)	3000 µg	**[2]**
Niacin	900 mg	**[2]**
Vitamin B6	25 mg	**[2]**
Folate	1170 µg	**[2]**
Vitamin D	100 µg	**[2]**
Vitamin E	300 mg	**[2]**
Calcium	2500 mg	**[2]**
Copper	10 mg	**[2]**
Iodine	600 µg	**[2]**
Dissociable magnesium	250 mg	**[2]**
Selenium	300 µg	**[2]**
Zinc	25 mg	**[2]**

[1]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 were calculated as the sum of dietary niacin and 1/60 dietary tryptophan. The complete construction of the score has been described elsewhere [7, 8].

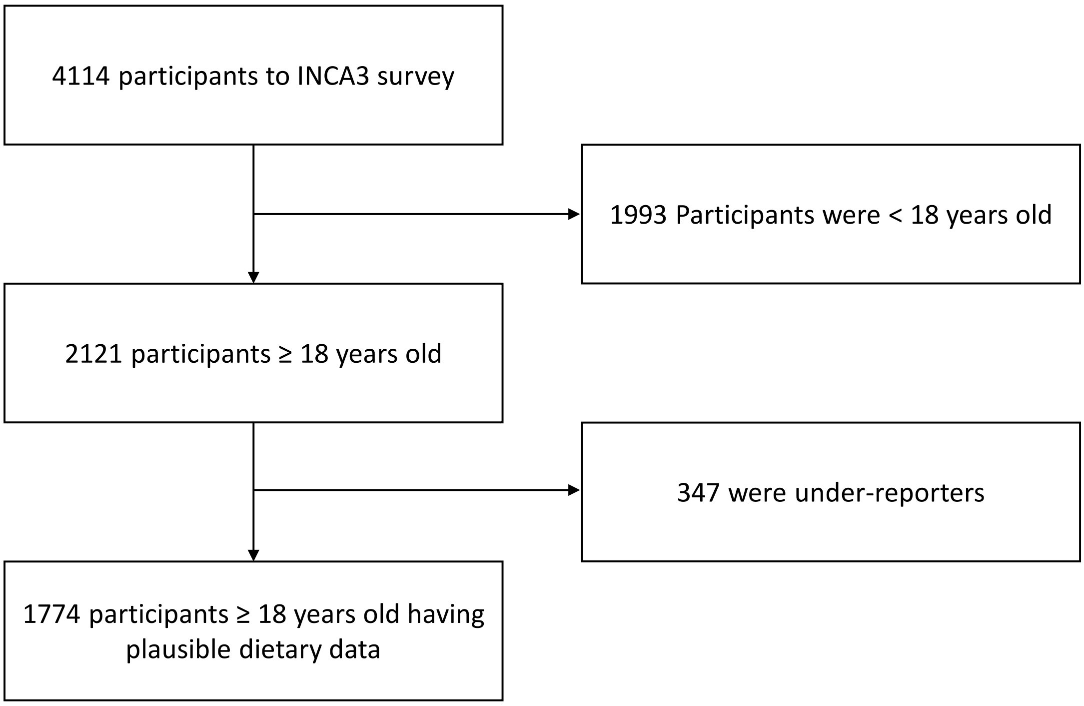
[2]The PANDiet 3.1 version is mainly based on the dietary reference intake from the 2016 Anses opinion [2]. PANDiet was modified from its previous version [8] in order to be used also in older adults [9]. According to ANSES opinion, the reference values for vitamins and minerals and the contribution of macronutrients to energy intake are similar to those of adults. Only protein intake should be higher (with a population reference intake of 1 g/kg/d vs 0.83 g/kg/d for younger adults). The reference value for proteins was therefore adapted for adults over the age of 65y.

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.

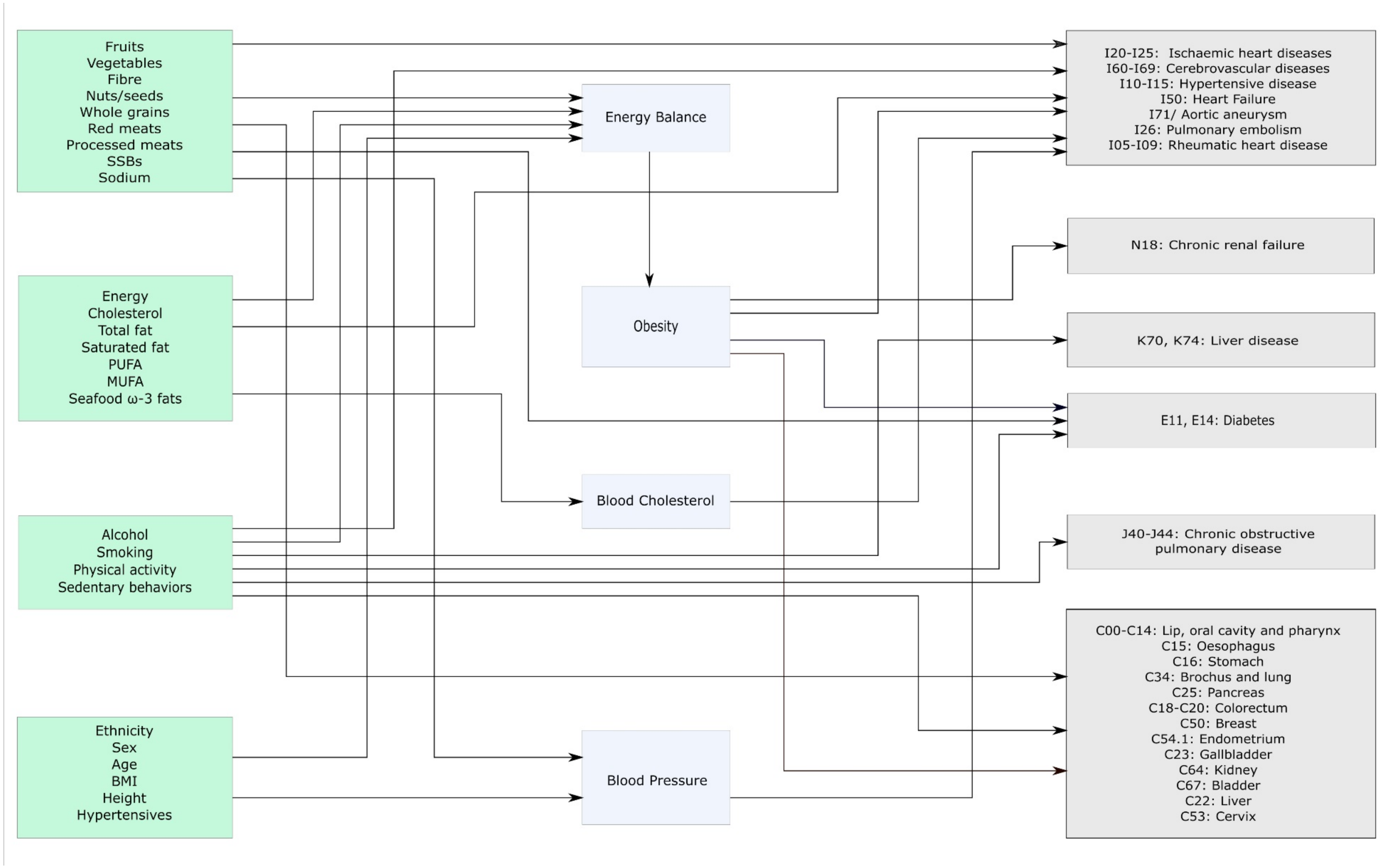
Supplementary Table S2 Food groups used to calculate PDI scores, and scoring system, as proposed by Satija et al. [10, 11]

	Overall plant-based diet index (PDI) (18-90 points)	**Healthy plant-based diet index (hPDI) (18-90 points)**	**Unhealthy plant-based diet index (uPDI) (18-90 points)**
	Plant Food Groups[1]		
Healthy			
Whole grains	Positive scores[2]	Positive scores	Reverse scores[3]
Fruits	Positive scores	Positive scores	Reverse scores
Vegetables	Positive scores	Positive scores	Reverse scores
Nuts	Positive scores	Positive scores	Reverse scores
Legumes	Positive scores	Positive scores	Reverse scores
Vegetable oils	Positive scores	Positive scores	Reverse scores
Tea and coffee	Positive scores	Positive scores	Reverse scores
Less healthy			
Fruit juices	Positive scores	Reverse scores	Positive scores
Refined grains	Positive scores	Reverse scores	Positive scores
Potatoes	Positive scores	Reverse scores	Positive scores
Sugar sweetened beverages	Positive scores	Reverse scores	Positive scores
Sweets and desserts	Positive scores	Reverse scores	Positive scores
	Animal Food Groups		
Animal fats	Reverse scores	Reverse scores	Reverse scores
Dairy	Reverse scores	Reverse scores	Reverse scores
Eggs	Reverse scores	Reverse scores	Reverse scores
Fish or seafood	Reverse scores	Reverse scores	Reverse scores
Meat	Reverse scores	Reverse scores	Reverse scores
Miscellaneous animal-based foods	Reverse scores	Reverse scores	Reverse scores

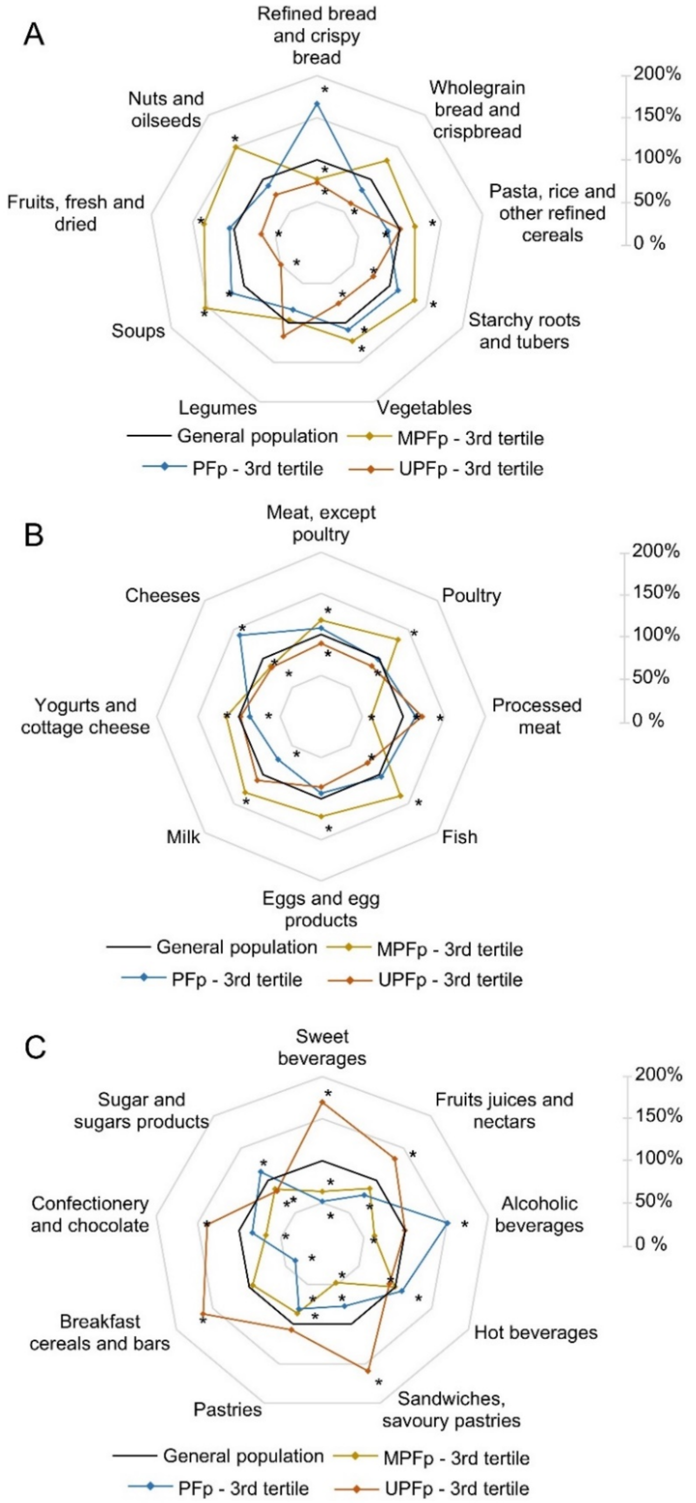
[1]Each food item was attributed to a food group (mixed foods were broken down into ingredients which were then attributed to a food group). The mean quantity of each food group consumed each day per individual was worked out instead of the frequencies of consumption, because our data came from 24h recalls and not a FFQ, as was the case in the study by Satija et al. The consumption of each food group was stratified into quintiles among participants. For each food group, a score between 1 and 5 was applied.
[2]For positive scores, the highest scores were attributed to the individuals in the highest consumption quintiles (i.e. 5 points for the 5th quintile to 1 point for the 1st quintile).
[3]For reverse scores, individuals in the higher quintiles received fewer points that individuals in the lower quintiles (i.e. 1 point for the 5th quintile to 5 point for the 1st quintile).



Supplementary Figure S1 Flow chart explaining the sampling of French participants from the third Individual and National Study on Food Consumption Survey (INCA3).



Supplementary Figure S2 A conceptual framework showing the relationship between the risk factors and the disease outcomes, implemented in the EpiDiet model. The left column lists the risk factors considered (foods, macro and micro-nutrients, behaviors and anthropometric measurements), and the right the diseases taken into account in the model. In the middle are listed the mechanistic or statistical models implemented in EpiDiet to formulate the hypotheses on the mediator factors.



Supplementary Figure S3 Relative mean intake of A. Plant-based food groups, B. Animal-based food groups and C. Miscellaneous food groups in the third tertiles of the proportion of unprocessed/minimally processed foods in the diet (MPFp-3rd tertile, n=591), the proportion of processed foods in the diet (PFp-3rd tertile, n=591) and the proportion of ultra-processed foods in the diet (UPFp-3rd tertile, n=591) shown as a percentage compared to ls-mean intake in the INCA3 population (n=1774), taken as the reference at 100%. Means are adjusted for the season of recall. * indicates significant difference vs. the general population. Between-subject variability is not shown for the sake of clarity.

Supplementary Table S3 Contingency table showing the frequency distribution (across tertiles) of the proportion of energy from unprocessed/minimally processed foods (MPF), processed foods (PF) and ultra-processed foods (UPF) in the diet of the French adult population[a].

			Proportion of total energy intake from PF			Proportion of total energy intake from UPF		
			Tertile 1 (n=591)	Tertile 2 (n=592)	Tertile 3 (n=591)	Tertile 1 (n=591)	Tertile 2 (n=592)	Tertile 3 (n=591)
Proportion of total energy intake from MPF	Tertile 1 (n=591)	n	136	186	269	87	150	354
		%	*7.67*	*10.48*	*15.16*	*4.9*	*8.46*	*19.95*
	Tertile 2 (n=592)	n	168	193	231	181	235	176
		%	*9.47*	*10.88*	*13.02*	*10.2*	*13.25*	*9.92*
	Tertile 3 (n=591)	n	287	213	91	323	207	61
		%	*16.18*	*12.01*	*5.13*	*18.21*	*11.67*	*3.44*
Proportion of total energy intake from UPF	Tertile 1 (n=591)	n	103	169	319			
		%	*5.81*	*9.53*	*17.98*			
	Tertile 2 (n=592)	n	173	222	197			
		%	*9.75*	*12.51*	*11.1*			
	Tertile 3 (n=591)	n	315	201	75			
		%	*17.76*	*11.33*	*4.23*			

[a]Data from the Individual and National Study on Food Consumption Survey 3, *n*=1774. MPF, unprocessed/minimally processed foods; PF, processed foods; UPF, ultra-processed foods.

Supplementary Table S4 Sociodemographic characteristics according to tertiles of the proportion of unprocessed/minimally processed foods (MPF), processed foods (PF) and ultra-processed foods (UPF) in the diet of the French adult population[a].

	All population (n=1774)	Proportion of total energy intake from MPF				Proportion of total energy intake from PF				Proportion of total energy intake from UPF			
		T1 (n=591) 1.01-27.66%	T2 (n=592) 27.67-37.68%	T3 (n=591) 37.69-76.91%	P^*	T1 (n=591) 0.00-19.58%	T2 (n=592) 19.59-30.21%	T3 (n=591) 30.22-69.47%	*P*	T1 (n=591) 0.12-20.62%	T2 (n=592) 20.68-34.06%	T3 (n=591) 34.13-78.92%	*P*
Sex, *% males*	49.9	56.6	48.9	43.0	<0.001	40.1	48.0	62.2	<0.001	48.5	49.5	51.4	0.603
Age group, *%*					<0.001				<0.001				<0.001
18-24 y	10.3	13.7	7.8	8.9		19.2	5.4	5.8		4.6	3.6	20.5	
25-34 y	15.9	23.4	12.5	10.5		20.9	15.1	11.5		4.1	15.2	25.7	
35-49 y	30.7	33.5	30.5	27.5		28.1	38.6	25.6		23.7	33.6	33.7	
50-65 y	25.8	20.3	30.1	27.9		21.0	23.1	33.6		34.4	32.0	13.8	
65-79 y	17.4	9.1	19.1	25.3		10.9	17.9	23.6		33.4	15.6	6.3	
Educational level, *%*					0.417				0.014				<0.001
Primary school	47.0	44.7	47.0	49.7		44.0	44.9	52.1		53.2	47.2	42.0	
Middle school	17.7	17.0	18.3	17.8		21.5	16.9	14.4		15.8	13.2	23.0	
Secondary school	17.4	19.3	17.8	14.7		16.8	18.1	17.3		14.7	18.8	18.3	
College or university	18.0	18.9	17.0	17.9		17.7	20.0	16.2		16.4	20.9	16.7	
Occupational status, *%*					<0.001				<0.001				<0.001
Employee	15.6	16.9	15.7	13.9		22.9	10.5	13.1		10.0	16.5	19.3	
Manual worker	13.1	14.8	14.1	9.8		13.6	15.1	10.5		7.0	13.1	17.8	
Farmer	0.7	0.6	0.6	0.9		0.1	1.0	0.9		1.0	0.9	0.2	
Craftsman, shopkeeper, business owner	3.3	3.1	3.4	3.5		2.4	2.5	5.2		4.4	4.3	1.7	
Intermediate profession	19.6	22.7	19.3	16.2		16.9	25.3	16.8		12.9	19.8	24.7	
Professional, executive	13.2	14.9	13.5	10.8		10.8	14.2	14.7		12.8	14.8	12.1	
Retired	23.1	13.8	25.7	31.6		14.9	22.5	32.4		44.3	20.5	8.8	
Inactive	11.4	13.1	7.7	13.3		18.5	9.1	6.4		7.6	10.2	15.5	
Region of France, *%*					0.001				0.005				0.238
Ile-de-France (Paris area)	17.4	16.0	16.3	20.4		18.4	15.7	18.1		17.9	19.1	15.6	
North-West	19.8	22.3	22.3	14.3		17.3	21.9	20.4		17.8	19.9	21.4	
North-East	27.2	26.8	29.9	24.7		28.5	30.5	22.5		24.8	28.5	27.9	
South-East	17.9	19.0	15.2	19.4		19.2	13.6	20.8		19.8	17.2	17.0	
South-West	17.7	16.0	16.3	21.3		16.6	18.3	18.3		19.7	15.3	18.2	
City size, *%*					<0.001				<0.001				<0.001
Rural	26.1	20.3	31.1	27.7		22.4	25.8	30.3		31.4	28.4	20.0	
2 000-19 999 hab.	17.6	19.8	18.5	14.0		15.5	16.0	21.4		19.0	17.8	16.3	
20 000-99 999 hab.	11.0	9.7	14.0	9.2		12.4	9.5	10.9		11.1	9.3	12.2	
≥100 000 hab.	32.4	37.1	27.0	32.6		33.5	36.9	26.8		25.9	31.7	38.1	
Paris agglomeration	13.0	13.1	9.5	16.5		16.3	11.8	10.7		12.6	12.8	13.4	

[a] Data from the Individual and National Study on Food Consumption Survey 3, *n*=1774. Values are percentages weighted for the survey design.
[*] *P* values are from χ^2 test. NS. "Refusals to answer" were included in the statistical test (for Matrimonial status and Perception of financial status)
MPF, unprocessed/minimally processed foods; NS, nonsignificant; PF, processed foods; T, tertile; UPF, ultra-processed foods; y, years old

Supplementary Table S4 (continued)

	All population (n=1774)	Proportion of total energy intake from MPF				Proportion of total energy intake from PF				Proportion of total energy intake from UPF			
		T1 (n=591) 1.01-27.66%	T2 (n=592) 27.67-37.68%	T3 (n=591) 37.69-76.91%	*P*	T1 (n=591) 0.00-19.58%	T2 (n=592) 19.59-30.21%	T3 (n=591) 30.22-69.47%	*P*	T1 (n=591) 0.12-20.62%	T2 (n=592) 20.68-34.06%	T3 (n=591) 34.13-78.92%	*P*
Season of record, *%*					<0.001				<0.001				0.417
Winter	24.5	20.8	21.9	31.8		32.5	22.0	18.7		25.2	24.3	24.1	
Spring	25.0	28.4	23.5	22.7		21.7	26.0	27.7		25.6	25.7	24.0	
Summer	25.6	30.4	25.5	19.9		22.7	27.3	26.9		23.5	23.8	28.7	
Autumn	24.9	20.5	29.2	25.6		23.2	24.8	26.8		25.7	26.2	23.1	
Matrimonial status, *%*					<0.001				<0.001				<0.001
Single	20.3	22.4	19.3	19.0		29.3	14.7	16.6		12.8	15.3	30.6	
Married	48.9	42.4	49.4	56.2		38.5	52.2	56.6		63.5	56.3	31.2	
Unmarried couple	19.3	24.9	20.8	11.0		20.2	20.0	17.7		11.5	17.8	26.7	
Widowed	3.5	2.6	3.3	4.7		3.6	3.1	3.7		4.5	3.3	2.8	
Separated/divorced	8.0	7.7	7.3	8.9		8.4	10.2	5.3		7.7	7.3	8.8	
Refusal to answer	0.0	0.0	0.0	0.1		0.0	0.0	0.1		0.1	0.0	0.0	
Perception of financial status, *%*					0.002				0.183				0.027
Financially comfortable	14.7	14.5	15.2	14.4		14.5	15.0	14.7		15.0	16.0	13.4	
It's okay	36.2	33.0	38.5	37.7		35.2	34.4	39.1		39.8	37.2	32.6	
It's tight	10.8	9.3	10.3	13.2		10.7	12.0	9.8		12.0	9.7	10.8	
Manageable if careful	29.5	31.3	31.1	25.5		29.4	30.3	28.7		27.3	28.7	31.8	
Hard to make ends meet	7.9	10.5	4.4	8.4		8.5	7.9	7.3		5.2	7.9	10.0	
Can't manage without debts	0.9	1.4	0.5	0.8		1.9	0.3	0.4		0.6	0.5	1.4	
Refusal to answer	0.0	0.0	0.1	0.0		0.0	0.1	0.0		0.1	0.0	0.0	
Food insufficiency, *%*					0.005				0.106				<0.001
Food sufficiency	83.2	79.0	85.5	85.9		80.7	83.8	85.2		87.1	84.7	78.9	
Qualitative food insufficiency	14.2	18.2	11.6	12.0		17.1	13.5	11.7		11.6	10.8	19.0	
Quantitative food insufficiency	2.6	2.8	2.9	2.1		2.3	2.6	3.0		1.4	4.5	2.0	
Food insecurity, *%*					<0.001				0.032				<0.001
Food security	92.1	87.1	96.7	93.2		90.3	91.5	94.5		95.3	94.1	87.9	
Moderate food insecurity	4.9	8.4	1.6	4.0		5.4	6.0	3.1		2.5	3.8	7.6	
Severe food insecurity	3.1	4.4	1.7	2.8		4.3	2.5	2.4		2.2	2.1	4.6	
Body Mass Index (BMI), %													
Underweight (BMI<18.5)	3.5	4.0	4.7	1.7	0.005	5.1	3.3	2.2	0.005	2.4	3.4	4.5	0.013
Normal weight (18.5≤BMI<25)	48.6	50.4	50.9	44.0		52.8	44.7	48.0		44.3	49.1	51.6	
Overweight (25≤BMI<30)	34.8	33.9	32.2	38.6		31.5	37.1	36.0		36.9	34.4	33.4	
Obesity (BMI≥30)	13.1	11.7	12.3	15.7		10.6	15.0	13.8		16.5	13.1	10.5	
BMI, kg/m² (mean ± SD)	25.3 ± 4.4	25.1 ± 4.5	25.1 ± 4.4	25.8 ± 4.4		24.6 ± 4.7	25.8 ± 4.4	25.5 ± 4.1		25.8 ± 4.7	25.3 ± 4.2	24.8 ± 4.8	

Supplementary Table S5 Total, plant and animal protein intakes and distribution of food families to animal or plant protein intake according to tertiles of the proportion of unprocessed/minimally processed foods (MPF), processed foods (PF) and ultra-processed foods (UPF) in the diet of the French adult population[a].

	All population (n=1774)		Proportion of total energy intake from MPF						Proportion of total energy intake from PF						Proportion of total energy intake from UPF					
			T1 (n=591)		T2 (n=592)		T3 (n=591)		T1 (n=591)		T2 (n=592)		T3 (n=591)		T1 (n=591)		T2 (n=592)		T3 (n=591)	
			1.01-27.66%		27.67-37.68%		37.69-76.91%		0.00-19.58%		19.59-30.21%		30.22-69.47%		0.12-20.62%		20.68-34.06%		34.13-78.92%	
	Mean	SEM	Mean[b]	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Total protein, g/d	81.7	0.4	76.8	0.7	81.8**	0.7	87.4**	0.7	78.7	0.7	82.2**	0.7	84.2**	0.7	83.3	0.8	82.7	0.7	79.4**	0.7
Animal protein, g/d	55.7	0.5	51.1	0.7	55.8**	0.8	61.0**	0.8	55.0	0.8	57.0	0.8	55.2	0.8	54.9	0.8	56.9	0.8	55.3	0.7
BI-APF	0.73	0.00	0.73	0.00	0.73	0.00	0.71**	0.00	0.72	0.00	0.73	0.00	0.72	0.00	0.71	0.00	0.73*	0.00	0.73**	0.00
Protein from animal-based families, % of animal protein																				
Red meat	24.2	0.5	21.3	0.7	25.3**	0.8	26.5**	0.8	24.8	0.8	24.3	0.8	23.4	0.8	24.2	0.8	25.1	0.8	23.3	0.7
Poultry	13.1	0.4	10.8	0.6	12.4	0.7	16.6**	0.7	14.3	0.6	12.3*	0.7	12.7	0.7	14.6	0.7	13.1	0.7	11.9*	0.6
Processed meat	12.2	0.3	16.9	0.4	11.5**	0.5	7.4**	0.5	10.9	0.5	12.6*	0.5	13.2**	0.5	9.8	0.5	10.9	0.5	15.2**	0.4
Fish	10.9	0.3	7.8	0.5	12.2**	0.6	13.3**	0.6	10.7	0.6	10.8	0.6	11.3	0.6	12.2	0.6	12.3	0.6	8.7**	0.5
Eggs	6.1	0.2	6.3	0.2	6.0	0.3	6.0	0.3	7.1	0.3	6.0*	0.3	5.1**	0.3	6.2	0.3	6.0	0.3	6.1	0.2
Milk	8.8	0.2	9.6	0.4	7.9*	0.4	8.6	0.4	11.2	0.4	8.8**	0.4	6.2**	0.4	6.6	0.4	7.7*	0.4	11.3**	0.4
Cheese	16.3	0.3	19.9	0.5	16.4**	0.5	11.8**	0.5	12.0	0.5	16.6**	0.5	20.4**	0.5	17.4	0.5	15.6*	0.5	15.8*	0.5
Yogurt	6.0	0.2	5.3	0.3	5.8	0.3	7.2**	0.3	7.0	0.3	6.1*	0.3	5.0**	0.3	6.1	0.3	6.7	0.3	5.4	0.3
Offal	1.1	0.1	1.0	0.2	1.2	0.2	1.2	0.2	0.7	0.2	1.3*	0.2	1.4*	0.2	1.4	0.2	1.1	0.2	0.9*	0.2
Game	0.2	0.1	0.1	0.1	0.2	0.1	0.5**	0.1	0.1	0.1	0.1	0.1	0.5*	0.1	0.6	0.1	0.2**	0.1	0.0**	0.1
Other dairy products	1.1	0.0	1.1	0.1	1.2	0.1	0.9*	0.1	1.2	0.1	1.1	0.1	0.9*	0.1	0.9	0.1	1.1*	0.1	1.1*	0.1
Plant protein, g/d	26.0	0.1	25.7	0.2	25.9	0.2	26.4*	0.3	23.7	0.2	25.3**	0.2	29.0**	0.2	28.4	0.2	25.8**	0.2	24.1**	0.2
Plant protein, % of total protein	33.2	0.2	35.0	0.4	33.0**	0.4	31.2**	0.4	31.7	0.4	32.2	0.4	35.7**	0.4	35.3	0.4	32.4**	0.4	32.2**	0.4
BI-PBF	0.59	0.00	0.55	0.01	0.60**	0.01	0.64**	0.01	0.64	0.01	0.61**	0.01	0.53**	0.01	0.58	0.01	0.61*	0.01	0.59	0.01
Protein from plant-based families, % of plant protein																				
Refined grains	55.0	0.4	60.7	0.7	55.7**	0.7	47.3**	0.7	48.8	0.7	54.1**	0.7	62.2**	0.7	54.8	0.8	53.6	0.8	56.1	0.7
Whole grains	5.3	0.2	4.1	0.4	5.6*	0.4	6.4**	0.4	5.7	0.4	5.9	0.4	4.3*	0.4	5.7	0.4	5.9	0.4	4.5*	0.4
Nuts and seeds	3.1	0.1	2.5	0.2	3.2*	0.2	3.8**	0.3	3.5	0.2	3.2	0.2	2.6*	0.2	3.1	0.3	3.4	0.2	2.9	0.2
Legumes	2.8	0.2	2.4	0.3	2.9	0.3	3.1	0.3	3.3	0.3	2.7	0.3	2.3*	0.3	2.5	0.3	3.0	0.3	2.9	0.3
Vegetables	12.6	0.2	9.4	0.3	12.4**	0.3	16.6**	0.3	13.6	0.3	12.6*	0.4	11.4**	0.4	14.9	0.4	12.6**	0.3	10.8**	0.3
Potatoes	7.1	0.2	6.1	0.3	6.7	0.3	8.7**	0.3	7.8	0.3	7.4	0.3	6.0**	0.3	7.5	0.3	7.4	0.3	6.5*	0.3
Fruits	5.9	0.1	4.6	0.2	5.8**	0.2	7.4**	0.2	6.9	0.2	5.7**	0.2	5.0**	0.2	6.3	0.2	6.1	0.2	5.3**	0.2
Other plant foods	8.3	0.2	10.3	0.3	7.7**	0.3	6.7**	0.3	10.3	0.3	8.3**	0.3	6.2**	0.3	5.1	0.3	8.0**	0.3	11.1**	0.2

[a] Data from the Individual and National Study on Food Consumption Survey 3, n=1774. Data were collected by three 24h recalls.
[b] Means adjusted for season of recall and weighted for the survey design. Significantly different from the mean of the first tertile: *, P<0.05; **, P<0.001; *P* ≥ 0.05, NS. P for ANOVA tests adjusted for season of recall.
BI-ABF: Berry-Index Animal-based families; BI-PBF: Berry-Index Plant-based families; MPF, unprocessed/minimally processed foods; NS, nonsignificant; PF, processed foods; SEM: standard error of the mean; T, tertile; UPF, ultra-processed foods.

Supplementary Table S6 PANDiet score and subscores and plant-based diet indices according to tertiles of the proportion of unprocessed/minimally processed foods (MPF), processed foods (PF) and ultra-processed foods (UPF) in the diet of the French adult population[a].

	All population (n=1774)		Proportion of total energy intake from MPF						Proportion of total energy intake from PF						Proportion of total energy intake from UPF					
			T1 (n=591) 1.01-27.66%		T2 (n=592) 27.67-37.68%		T3 (n=591) 37.69-76.91%		T1 (n=591) 0.00-19.58%		T2 (n=592) 19.59-30.21%		T3 (n=591) 30.22-69.47%		T1 (n=591) 0.12-20.62%		T2 (n=592) 20.68-34.06%		T3 (n=591) 34.13-78.92%	
	Mean	SEM	Mean[b]	SEM	Mean	SEM	Mean	SEM	Mean[2]	SEM	Mean	SEM	Mean	SEM	Mean[2]	SEM	Mean	SEM	Mean	SEM
PANDiet score (0-100)	64.3	0.14	62.6	0.22	64.5**	0.24	66.2**	0.24	63.5	0.24	64.2*	0.24	65.3**	0.24	65.3	0.25	65.0	0.24	62.9**	0.22
AS (0-100)	63.6	0.31	62.2	0.51	64.7*	0.54	64.2*	0.56	61.6	0.53	64.0*	0.54	65.4**	0.54	64.7	0.57	64.1	0.54	62.3*	0.50
Probabilities of adequacy for AS components (0-1)																				
Protein	0.89	0.00	0.89	0.01	0.91	0.01	0.87	0.01	0.86	0.01	0.89*	0.01	0.92**	0.01	0.87	0.01	0.90*	0.01	0.90*	0.01
LA	0.43	0.01	0.46	0.01	0.41*	0.01	0.42*	0.01	0.49	0.01	0.46	0.01	0.34**	0.01	0.34	0.01	0.45**	0.01	0.48**	0.01
ALA	0.11	0.00	0.11	0.01	0.11	0.01	0.11	0.01	0.13	0.01	0.10*	0.01	0.09*	0.01	0.10	0.01	0.12	0.01	0.10	0.01
DHA	0.22	0.01	0.15	0.01	0.25**	0.01	0.28**	0.01	0.22	0.01	0.23	0.01	0.23	0.01	0.25	0.01	0.23	0.01	0.19*	0.01
EPA+DHA	0.20	0.01	0.14	0.01	0.22**	0.01	0.25**	0.01	0.19	0.01	0.20	0.01	0.20	0.01	0.22	0.01	0.21	0.01	0.17*	0.01
Fiber	0.39	0.01	0.37	0.01	0.40	0.01	0.41	0.01	0.35	0.01	0.38*	0.01	0.45**	0.01	0.46	0.01	0.38**	0.01	0.34**	0.01
Vitamin A	0.52	0.01	0.49	0.01	0.56*	0.01	0.51	0.01	0.46	0.01	0.53**	0.01	0.56**	0.01	0.60	0.01	0.51**	0.01	0.47**	0.01
Thiamin	0.96	0.00	0.96	0.00	0.96	0.00	0.97**	0.00	0.96	0.00	0.97*	0.00	0.97*	0.00	0.96	0.00	0.97	0.00	0.96	0.00
Riboflavin	0.76	0.01	0.75	0.01	0.78	0.01	0.75	0.01	0.71	0.01	0.77**	0.01	0.80**	0.01	0.77	0.01	0.77	0.01	0.75	0.01
Niacin	1.00	0.00	1.00	0.00	1.00*	0.00	1.00*	0.00	0.99	0.00	1.00**	0.00	1.00**	0.00	1.00	0.00	1.00*	0.00	1.00	0.00
Pantothenic acid	0.87	0.00	0.85	0.01	0.89**	0.01	0.88*	0.01	0.84	0.01	0.88**	0.01	0.89**	0.01	0.87	0.01	0.88	0.01	0.86	0.01
Vitamin B-6	0.69	0.01	0.64	0.01	0.71**	0.01	0.74**	0.01	0.65	0.01	0.69*	0.01	0.73**	0.01	0.73	0.01	0.71	0.01	0.64**	0.01
Folate	0.66	0.01	0.61	0.01	0.70**	0.01	0.69**	0.01	0.63	0.01	0.66	0.01	0.70**	0.01	0.72	0.01	0.68*	0.01	0.61**	0.01
Vitamin B-12	0.65	0.01	0.62	0.01	0.66*	0.01	0.67*	0.01	0.61	0.01	0.65*	0.01	0.69**	0.01	0.66	0.01	0.66	0.01	0.63	0.01
Vitamin C	0.43	0.01	0.34	0.01	0.44**	0.02	0.52**	0.02	0.43	0.02	0.45	0.02	0.39	0.02	0.49	0.02	0.43*	0.02	0.37**	0.01
Vitamin D	0.03	0.00	0.03	0.00	0.04	0.00	0.04	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.04	0.00	0.03	0.00	0.03	0.00
Vitamin E	0.80	0.00	0.81	0.01	0.80	0.01	0.79	0.01	0.80	0.01	0.81	0.01	0.79	0.01	0.78	0.01	0.81*	0.01	0.81*	0.01
Iodine	0.72	0.01	0.71	0.01	0.72	0.01	0.74*	0.01	0.69	0.01	0.73*	0.01	0.75**	0.01	0.75	0.01	0.72	0.01	0.70*	0.01
Magnesium	0.48	0.01	0.48	0.01	0.50	0.01	0.48	0.01	0.47	0.01	0.45	0.01	0.53*	0.01	0.48	0.01	0.49	0.01	0.48	0.01
Phosphorus	0.97	0.00	0.96	0.00	0.98**	0.00	0.97**	0.00	0.96	0.00	0.98**	0.00	0.98**	0.00	0.97	0.00	0.98	0.00	0.96**	0.00
Potassium	0.66	0.01	0.64	0.01	0.68*	0.01	0.67*	0.01	0.61	0.01	0.66*	0.01	0.71**	0.01	0.70	0.01	0.67	0.01	0.62**	0.01
Selenium	0.95	0.00	0.93	0.00	0.95*	0.00	0.95*	0.00	0.94	0.00	0.95	0.00	0.95	0.00	0.94	0.00	0.95	0.00	0.94	0.00
Absorbed zinc	0.29	0.01	0.29	0.01	0.30	0.01	0.27	0.01	0.30	0.01	0.28	0.01	0.29	0.01	0.26	0.01	0.27	0.01	0.33**	0.01
Copper	0.91	0.00	0.91	0.01	0.92	0.01	0.89	0.01	0.88	0.01	0.91**	0.01	0.93**	0.01	0.91	0.01	0.91	0.01	0.90	0.01
Manganese	0.90	0.00	0.90	0.01	0.92	0.01	0.89*	0.01	0.87	0.01	0.91**	0.01	0.93**	0.01	0.91	0.01	0.91	0.01	0.89*	0.01
Calcium	0.64	0.01	0.67	0.01	0.64	0.01	0.60*	0.01	0.59	0.01	0.66**	0.01	0.66**	0.01	0.63	0.01	0.64	0.01	0.64	0.01
Absorbed iron	0.61	0.01	0.61	0.01	0.63	0.01	0.59	0.01	0.56	0.01	0.61**	0.01	0.68**	0.01	0.63	0.01	0.61	0.01	0.60*	0.01
MS (0-100)	65.0	0.23	63.0	0.37	64.3*	0.40	68.1**	0.41	65.4	0.39	64.5	0.40	65.2	0.40	66.0	0.42	65.9	0.40	63.5**	0.37
Probabilities of adequacy for MS components (0-1)																				
Protein	0.94	0.00	0.93	0.01	0.94	0.01	0.94	0.01	0.93	0.01	0.95	0.01	0.92	0.01	0.93	0.01	0.95	0.01	0.93	0.01
Carbohydrates	0.94	0.00	0.93	0.00	0.94	0.01	0.95*	0.01	0.94	0.00	0.97**	0.01	0.92**	0.01	0.92	0.01	0.95**	0.01	0.95**	0.00
Total fat	0.92	0.00	0.92	0.01	0.91	0.01	0.92	0.01	0.91	0.01	0.90	0.01	0.94**	0.01	0.93	0.01	0.91*	0.01	0.92	0.01
SFA	0.30	0.01	0.27	0.01	0.27	0.01	0.35**	0.01	0.32	0.01	0.24**	0.01	0.33	0.01	0.35	0.01	0.28**	0.01	0.26**	0.01
Sugars (without lactose)	0.65	0.01	0.61	0.01	0.65	0.01	0.71**	0.01	0.59	0.01	0.66**	0.01	0.71**	0.01	0.69	0.01	0.69	0.01	0.59**	0.01
Sodium	0.18	0.00	0.15	0.01	0.16	0.01	0.24**	0.01	0.26	0.01	0.16**	0.01	0.12**	0.01	0.17	0.01	0.19	0.01	0.19	0.01
PDI (18-90)	52.1	0.14	51.3	0.24	51.9	0.25	53.5**	0.26	52.1	0.25	51.9	0.25	52.4	0.25	53.5	0.26	52.1**	0.25	51.1**	0.23
hPDI (18-90)	52.4	0.16	51.4	0.26	52.4*	0.27	53.4**	0.28	51.2	0.27	52.3*	0.27	53.6**	0.27	54.4	0.28	53.0**	0.27	50.1**	0.25
uPDI (18-90)	55.6	0.18	58.4	0.29	55.1**	0.30	53.0**	0.32	56.3	0.31	55.3*	0.32	55.2*	0.32	53.7	0.32	54.1	0.31	58.4**	0.28

[a] Data from the Individual and National Study on Food Consumption Survey 3, n=1774. Data were collected by three 24h-recalls.

[b] Means adjusted for season of recall and weighted for the survey design. Significantly different from the mean of the first tertile: *, P<0.05; **, P<0.001; *P* ≥ 0.05, NS. P for ANOVA tests adjusted for season of recall.

ALA, alpha-linolenic acid; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; hPDI, healthy Plant-based Diet Index; LA, linoleic acid; MPF, unprocessed/minimally processed foods; NS, non-significant; PANDiet, Probability of Adequate Nutrient Intake; PF, processed foods; SEM: standard error of the mean; SFA, saturated fatty acids; T, tertile; uPDI, unhealthy Plant-based diet Index, UPF, ultra-processed foods.

Supplementary Table S7 Predicted number of deaths avoided from cerebrovascular diseases, ischemic heart diseases and diabetes by each nutritional factor weighted in the comparative risk assessment using the EPIDiet model, in the context of a shift of the population's diet from the first tertile to the third tertile of the proportion of unprocessed/minimally processed foods (MPF), processed foods (PF) and ultra-processed foods (UPF) in the diet in the French adult population[a].

	Proportion of total energy intake from MPF – T3 vs T1			Proportion of total energy intake from PF – T3 vs T1			Proportion of total energy intake from UPF – T3 vs T1		
	Cerebrovascular diseases	Ischemic heart diseases	Diabetes	Cerebrovascular diseases	Ischemic heart diseases	Diabetes	Cerebrovascular diseases	Ischemic heart diseases	Diabetes
Death avoided or added by nutritional factors[b] (number)									
Whole grains	204	125	109	-177	-119	-104	-44	-16	-19
PUFA	38	474	NA	-3	-642	NA	-30	18	NA
Nuts & Seeds	NA	642	249	NA	-662	-245	NA	-19	-30
SFA	-36	-39	NA	-3	101	NA	31	-75	NA
MUFA	-18	-213	NA	-7	25	NA	25	133	NA
Dietary cholesterol	-3	-29	NA	2	-44	NA	8	64	NA
Seafood omega-3 fats	NA	800	NA	NA	-16	NA	NA	-703	NA
Vegetables	1017	419	NA	-226	-89	NA	-1049	-405	NA
Fibers	318	515	NA	-116	-118	NA	-192	-383	NA
Processed meats	NA	1157	364	NA	-14	-13	NA	-2164	-852
Total fat	-37	-113	NA	-6	142	NA	40	-87	NA
Fruits	814	504	NA	-421	-231	NA	-361	-182	NA
Sodium	245	260	NA	-389	-396	NA	179	177	NA
Alcohol	-27	-375	-93	-172	255	91	-285	94	-16
Red meats unprocessed	NA	NA	-124	NA	NA	7	NA	NA	51
SSB	-31	212	NA	-43	201	-22	-34	-527	-153
Death avoided or added because of energy intake and BMI[b] (number)									
Total energy	213	401	223	-193	-348	-209	63	90	57
BMI	180	375	167	-235	-391	-286	29	36	13
Total death avoided[b] (number)	2419 (2216, 2621)	4023 (3744, 4303)	665 (572, 759)	-1911 (-2109, -1713)	-1419 (-2097, -741)	-560 (-931, -188)	-1880 (-2165, -1595)	-5447 (-9439, -1457)	-1066 (-2248, 117)
Percentage deaths avoided[b] (%)	24.9 (22.8, 27.0)	30.9 (28.8, 33.0)	18.5 (15.9, 21.1)	-19.7 (-21.7, -17.6)	-10.9 (-16.1, -5.7)	-15.6 (-25.9, -5.2)	-19.4 (-22.3, -16.4)	-41.8 (-72.5, -11.2)	-29.6 (-62.5, 3.2)

[a] Dietary data from the Individual and National Study on Food Consumption Survey in France (INCA3). Data were collected by three 24h-recalls.
[b] Based on the numbers of disease-specific deaths observed in France in 2014. Negative values correspond to increasing deaths and positive values to decreasing deaths.
MPF, unprocessed/minimally processed foods; MUFA; Monounsaturated fatty acids; NA: Not applicable within the scope of this study; PF, processed foods; PUFA: Polyunsaturated fatty acids; SFA, Saturated fatty acids; SSB, sugar-sweetened beverage; T1: 1st tertile; T3: 3rd tertile; UPF, ultra-processed foods.

References

1. Food and Agriculture Organization of the United Nations (2013) Dietary protein quality evaluation in human nutrition: report of an FAO expert consultation, 31 March-2 April, 2011, Auckland, New Zealand. Food and Agriculture Organization of the United Nations, Rome

2. Anses (2016) Actualisation des repères du PNNS : élaboration des références nutritionnelles. French Agency for Food, Environmental and Occupational Health Safety (Anses)., Maisons-Alfort, France

3. Anses (2011) Actualisation des apports nutritionnels conseillés pour les acides gras. French Agency for Food, Environmental and Occupational Health Safety (Anses)., Maisons-Alfort, France

4. EFSA (European Food Safety Agency) (2017) Dietary Reference Values for nutrients: Summary report. 92. https://doi.org/10.2903/sp.efsa.2017.e15121

5. EFSA NDA Panel (EFSA Panel on Nutrition, Novel Foods and Food Allergens) (2016) Scientific opinion on Dietary Reference Values for vitamin B6. EFSA Journal

6. de Gavelle E, Huneau J-F, Mariotti F (2018) Patterns of Protein Food Intake Are Associated with Nutrient Adequacy in the General French Adult Population. Nutrients 10:226. https://doi.org/10.3390/nu10020226

7. Verger EO, Mariotti F, Holmes BA, et al (2012) Evaluation of a Diet Quality Index Based on the Probability of Adequate Nutrient Intake (PANDiet) Using National French and US Dietary Surveys. PLoS ONE 7:e42155. https://doi.org/10.1371/journal.pone.0042155

8. de Gavelle E, Huneau J-F, Fouillet H, Mariotti F (2019) The Initial Dietary Pattern Should Be Considered when Changing Protein Food Portion Sizes to Increase Nutrient Adequacy in French Adults. The Journal of Nutrition 149:488–496. https://doi.org/10.1093/jn/nxy275

9. Anses (2019) Anses Opinion on the updating of the PNNS dietary guidelines for women from menopause and men over 65 years of age. French Agency for Food, Environmental and Occupational Health Safety (Anses)., Maisons-Alfort, France

10. Satija A, Bhupathiraju SN, Rimm EB, et al (2016) Plant-Based Dietary Patterns and Incidence of Type 2 Diabetes in US Men and Women: Results from Three Prospective Cohort Studies. PLoS Med 13:e1002039. https://doi.org/10.1371/journal.pmed.1002039

11. Satija A, Bhupathiraju SN, Spiegelman D, et al (2017) Healthful and Unhealthful Plant-Based Diets and the Risk of Coronary Heart Disease in U.S. Adults. Journal of the American College of Cardiology 70:411–422. https://doi.org/10.1016/j.jacc.2017.05.047