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Limited risks of nutrient deficiency and significant modelled health
benefits of adherence to a moderate plant-based diet in French adults

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Abstract

Purpose: In Western countries, plant-based diets could lead to long-term health benefits but also carry some risks of nutrient inadequacy. Here, we estimated the nutritional risks and health benefits of adopting plant-forward diets.

Methods: Based on the latest French representative survey (INCA3), we identified a subgroup of adults with more plant-based (PB+) diets characterized by both protein and energy intakes from plants >80th percentile. We compared the prevalence of nutrient inadequacy, excess intake, and risk of overt deficiency in PB+ and in the rest of the population (PB-) and evaluated the hypothetical burden of disease (as Disability Adjusted Life Years, DALYs) if the entire population shifted to the PB+ diet, using a comparative risk assessment framework.

Results: Compared to PB-, in PB+ (10.7% of the population; 52% male), the prevalence of inadequacy was lower for fibre, linoleic acid, potassium, and vitamin C and higher for selenium, protein, calcium, riboflavin, vitamins A, B6, B12, iron, and iodine. We also found a higher risk of overt deficiency in PB+ for iodine and riboflavin. Fewer PB+ exceeded the upper limit for Saturated Fatty Acids (SFA), but more exceeded the one set for sugars. Shifting to a PB+ diet would benefit population health, with ~132,700 [~125,400-~140,000, 95% UI] DALYs averted, the gain being ca. twice higher for males than females but related to the same main diseases (ischemic heart diseases, diabetes, and colorectal cancer). Benefits would stem from lower processed meat and SFA in both sexes, higher nuts consumption, and blood cholesterol reduction in females, and higher fruit consumption and fibre intake in males.

Conclusion: Despite suboptimal diet quality, significant nutritional risks were limited in PB+, especially regarding deficiency risk, while such diets would benefit long-term health.

Abbreviations:

aDT: average Deficiency Threshold

AI: Adequate Intake

DALYs: Disability Adjusted Life Years

DAs: (premature) Deaths Avoided

EAR: Estimated Average Requirement

EpiDiet: Evaluate the Potential Impact of a Diet

hPDI: Healthful Plant-based Diet Index

oPDI: Overall Plant-based Diet Index

PANDiet: Probability of Adequate Nutrient intake Diet index

PB-: Less plant-based

PB+: More plant-based

PDI: Plant-based Diet Index

SecDiet: Nutrient Security Diet index

UL: Tolerable upper intake level

uPDI: Unhealthful Plant-based Diet Index"

Keywords: plant-based diets, risk and benefit assessment, nutrient adequacy, comparative risk assessment, DALYs

Introduction

Plant-based diets have been associated with long-term health [1, 2], including lower risks of type-2 diabetes [3], ischemic heart diseases [4] and cancer [4]. On the other hand, animal products contribute significantly to the intake of indispensable nutrients such as iron, zinc, or vitamin B12 [5]. Therefore, transitioning to more plant-based diets raises concerns about possible nutrient shortages [6].

Those benefits and potential risks have been studied in vegetarians and vegans, who are usually found in a cultural, historical, and societal context [7]. While concerns about some nutrients (e.g., vitamin B12) could rise along the level of eviction of animal products [8], some concerns about nutrient shortage can much differ within the spectrum of vegetarian diets. For example, concerns have been raised about (bioavailable) iron and zinc for both lacto-ovo-vegetarians and vegans [9, 10], whereas concerns about calcium and iodine are specific to vegans [5, 11]. In contrast to the literature about the spectrum of vegetarian diets, little is known in populations that are more newly adopting plant-forward diets (*i.e.*, diets that rely more on plants but without clear eviction of some animal foods)[12, 13]. In that context, adopting a more plant-based diet is more driven by environmental or ethical than health reasons [14, 15], and because of related dietary differences the nutritional risks associated with these diets cannot be a priori inferred from those of vegetarians. Plant-forward diets offer less contrast than vegetarian diets, but in countries where there is no tradition of vegetarianism, these diets are adopted by a significant proportion of the population[16]. It is therefore necessary to assess the benefits and risks of these diets in relation to the current situation, but also with a view to the transition to such plant-forward diets by a larger part of the population. Indeed, there is a lack of data characterizing plant-forward diet in a representative sample in western countries. In the literature, the work that has been done on this subject is essentially modelling work that has sought to appreciate the impact of specific changes in observed diets, for instance by modelling decreases in meat[17, 18], or modelling the utilization of plant-based analogues[19–21]. Although these studies are very useful to analyse the importance of a few particular dietary factors,

they cannot provide information about the more complex and subtle changes that occur in reality with plant-forward diets. Benefits of plant-forward diets have been reported for moderately higher levels of plants in the diet. In particular, a higher plant-based diet index (PDI) has been associated with lower risks of diabetes [22], cardiovascular disease [23], coronary heart disease [24] and total mortality [25]. However, as stated above, the type of plant-forward diet could be different in a representative sample in Western countries as compared to cohort studies.

Here, using a representative national survey, we chose to study the French population, which has a predominantly animal-based diet, similar to other Western countries, with a small proportion of the population having more plant-based diets, thus providing a perspective for possible future dietary changes in the general population. We aimed to provide a detailed analysis of the nutritional risks and health benefits of consuming more plant-based (PB+) diets observed within a subsample of the French population. For a wide set of nutrients, we estimated the prevalence of nutrient inadequacy and excess intake and the risk of overt deficiency in the PB+ eaters and the rest of the population (PB- eaters). Finally, we evaluated the hypothetical burden of disease if the entire population was shifting to the PB+ diet, using a comparative risk assessment framework. Lastly, examining the contributors to these risks and benefits, we provided an analysis of the determinants of the varied dimensions of the nutritional and health risks.

Materials and methods

Study Population

The studied population was derived from the Third French Individual and National Food Consumption Survey (INCA3), a cross-sectional survey conducted between February 2014 and September 2015 in mainland France and aimed at estimating the food consumption and eating habits of individuals living in France [26]. The methodology and design of this nationwide representative survey have been fully described by Dubuisson *et al.* [27]. In brief, individuals were selected according to a three-stage cluster sampling design (geographical units, households and

individuals), based on the 2011 annual national census, with geographical stratification (region, size of urban area) in order to ensure national representativeness. Two independent random samples were drawn: a “Child” sample (0 to 17 years of age) and an “Adult” sample (18 to 79 years of age) [26]. During INCA3, the dietary intakes of adults were assessed using two-to-three non-consecutive 24 h recalls spread over around three weeks and covering both week and weekend days. Only adults (n=2121) were included in this study, and under-reporters were excluded from further analyses. Under-reporting individuals for energy intake were identified using the basal metabolic rate estimated by Henry’s equation [28] and the cut-off values proposed by Black [29]. Additionally, due to their specific nutrient requirements, pregnant and lactating females, as well as individuals aged over 65 years, were excluded, resulting in a subpopulation of 1365 individuals aged 18 to 65 years (593 males and 772 females). When no information was available regarding pregnancy or breastfeeding, females were considered neither pregnant nor lactating and included in the study. Females for whom information on menstruation was missing (n=58) were supposed to have reached menopause if they were over 50.

Compliance with a plant-based diet

We identified individuals adopting the most plant-based diets based on the shares of energy (excluding alcohol) and protein intakes both from foods of plant origin. These two variables ((1) share of energy intake from foods of plant origin and (2) share of protein intake from foods of plant origin) were calculated for each individual, using recipes to break down complex mixed dishes into animal- and plant-based ingredients. We defined the individuals following the most plant-based diets (“more plant-based” or PB+ eaters) as those whose shares of (1) energy and (2) protein intakes from plant-based foods were equal to or greater than the 80th percentile of the study population. The double cut-off at the 80th percentile resulted in a sub-sample of individuals with a sufficiently specific “more plant-based” diet and sufficient in number (n=146) for further analysis.

We then described dietary patterns of the PB+ and PB- and assessed their level of adherence to more plant-based diets using the Plant-based Diet Indices (PDI) developed by Satija et al. [22].

Food composition and nutrient intakes

We calculated nutrient intakes using the 2016 French food composition database run by the French Information Centre on Food Quality (CIQUAL: *Centre d'Information sur la Qualité de l'Alimentation*) [30]. To account for the poorer digestibility of plant protein compared to animal protein, we applied a 5% penalty to protein intake from plant food items as previously described [31]. Amino acid intake was calculated using an amino acid database based on published French analysis and international databases [18]. Finally, we estimated the bioavailable fractions of dietary total iron and zinc using reference equations [32–34], as previously described [35]. Data on dietary supplement consumption were not considered.

Individual nutrient adequacy and security

We measured individual nutrient adequacy and security using version 3.2 of the PANDiet score [20, 36] and the SecDiet score [37], respectively.

Briefly, the PANDiet score measures at the individual level the likelihood of having an overall adequate nutrient intake. It is the mean of two subscores: (1) an Adequacy Subscore (AS), calculated as the average of the probabilities of adequacy for 27 nutrients for which an Estimated Average Requirement (EAR) or an Adequate Intake (AI) has been set (namely protein, linoleic acid, α -linolenic acid, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), fibre, vitamin A, thiamine, riboflavin, niacin, vitamin B5, vitamin B6, folate, vitamin B12, vitamin C, vitamin D and E, calcium, copper, iodine, iron, magnesium, manganese, phosphorus, potassium, selenium and zinc), multiplied by 100, and (2) a Moderation Subscore (MS), corresponding to the average of the non-exceedance probabilities for 6 nutrients at risk of being exceeded for which a tolerable upper intake level (UL) is defined (namely protein, total carbohydrates, total sugars (i.e. mono- and di-saccharides excluding lactose and galactose), total fat, saturated fatty acids (SFA) and sodium), multiplied by 100.

In addition, the Moderation Subscore is partially weighed by a penalty system accounting for the exceedance of the ULs of 11 nutrients at low risk of excessive intake (namely vitamin A, B3 (niacin), B6, B9 (folate), vitamin D, calcium, copper, iodine, dissociable magnesium, selenium and zinc). Individual Adequation Subscore and Moderation Subscore and PANDiet scores range from 0 to 100, a higher score indicating better nutrient adequacy, moderation, or quality of the diet, respectively.

The SecDiet is another probability of adequate intake that measures at the individual level the likelihood of not having an overt nutrient deficiency. It corresponds the mean of the squared probabilities of not being at risk of deficiency for a subset of 12 nutrients for which a deficiency due to an insufficient intake has been described (namely vitamins A, B1 (thiamine), B2 (riboflavin), B3 (niacin), B9 (folate), B12, C, calcium, iodine, iron, selenium and zinc). The score varies between 0 and 1, with 1 corresponding to the lowest risk of overall nutrient deficiency.

Both scores are mainly based on the most recent French dietary reference values [38]. Details about the nutrient reference values used for PANDiet and SecDiet calculations are available in **Supplementary Information (Table S1 and Table S2)**.

Prevalence of inadequacy, excess nutrient intake, and deficiency risk

Nutrient inadequacy and deficiency both relate to having nutrient intake that are lower than recommended, resulting in a risk: nutrient inadequacy refers to having an intake lower than the requirement whereas nutrient overt deficiency refers to an even lower intake that would lead to functional impairment of the body manifesting as clinical signs [37]. On the other hand, excess nutrient intake corresponds to intakes beyond the tolerable upper intake level (UL), defined by the World Health Organization as the “maximum intake [...] that is unlikely to pose risk of adverse health effects from excess in almost all (97.5%) apparently healthy individuals in an age- and sex-specific population group” [39].

We estimated the prevalence of inadequacy for 27 nutrients (the ones accounted for in the Adequation Subscore of the PANDiet) and the prevalence of risk of overt

deficiency for 12 nutrients (those of the SecDiet index). The prevalence of excess nutrient intake was estimated for protein, SFA, sodium, and sugars.

We estimated prevalence in the population of PB+ eaters and the rest of the study population (PB- eaters) using the simplified Nusser method (also known as S-Nusser) [40, 41]. Briefly, for each nutrient, we normalized the distribution of the observed daily intakes within the different populations using BoxCox transformation. The distributions of usual intakes were then derived from those of observed intakes by subtracting the day-to-day intraindividual variance of the intakes measured from 3 separated recalls from the variance of the observed mean intakes. We back-transformed the distribution parameters and used a Monte Carlo simulation of 1,000,000 individuals to estimate the distribution of the usual intakes in the population. Finally, we estimated inadequacy as follows. For nutrients for which an EAR was set, we estimated the prevalence of people not meeting their requirements using a probabilistic approach [42]. For the nutrients for which only an AI was available, we estimated the prevalence of inadequacy using a simple cut-point method. The estimation method used (probabilistic approach or cut-point method) is available for each nutrient in **Supplementary Table S3**. As for setting the cut-off points, we distinguished between the AIs derived from physiological criteria and those simply based on intakes observed in a healthy population, which had been set using the overall French adult population. AIs derived from physiological criteria were used directly as cut-offs. When the AI was only based on observed data, the cut-off was set at the 5th percentile of individual intakes among the study population. We estimated the prevalence of risk of overt deficiency and excess nutrient intake following a cut-point method, using, respectively, average deficiency thresholds (aDTs) as defined by Salomé et al. [37] and ULs as cut-off points. All cut-off points are summarized in Supplementary Table S3.

Impact of the diet on long-term health

The impact of a more plant-based dietary pattern on long-term health was evaluated with the EpiDiet (Evaluate the Potential Impact of a Diet) model, a simulation-based nutritional and epidemiological model implementing the comparative risk

assessment framework. As previously described [43], the model quantifies the positive and negative impacts of diet changes on a population's long-term health. Comparative risk assessment involves defining a baseline scenario to which a counterfactual scenario is compared. In this study, the observed diet of the French 18-to-65-year-old population (PB+ and PB- eaters) was used as the baseline, and the diet of the PB+ eaters as the counterfactual scenario. The burden of disease was expressed in terms of disability-adjusted life years (DALYs) added or averted, as well as deaths avoided or caused (DAs).

In each scenario, the population was stratified by sex and age. These groups were based on sex-specific age terciles among the more plant-based eaters. The final age groups were rounded to 18-to-35 years, 36-to-50 years, and 51-to-65 years.

Factors included in the EpiDiet model are displayed in **Supplementary Figure S2**. In this general framework encompassing all characterized risk factors, since we intended to specifically assess the effect of the dietary pattern itself, and not that of other associated risk factors (such as smoking, physical activity, sedentary behaviours, height, alcohol intake), we retained in the model only the risk factors related to the consumption of food groups and nutrient intakes. In other words, although available in the model, we did not consider smoking, physical activity, sedentary behaviours, and alcohol consumption. We also chose to adjust for energy intake and discard BMI as a risk factor as it was considered a potential intermediary risk factor, not a dietary factor. Therefore, the comparative risk assessment was designed to evaluate the health effects of a change in the population's diet apart from changes in energy levels. Details regarding the EpiDiet model and its application to the present study are available in **Supplementary Method 2**.

Statistical analyses

To account for the complex survey design of INCA3, when available, analyses were computed using survey analysis procedures (PROC SURVEYMEANS, PROC SURVEYFREQ, and PROC SURVEYREG) of SAS Statistical Software (version 9.4). As regards descriptive statistics, categorical variables are presented as percentages, and differences between PB+ and PB- eaters were assessed by First-

order Rao-Scott chi-Square tests. Continuous variables are presented as means \pm SEM, and differences between PB+ and PB-eaters were determined by T-test.

Figures of prevalence of inadequacy, excess nutrient intake, and deficiency risk are presented as percentages with a 95% CI calculated using the Wilson score interval with continuity correction. It should be noted that due to the absence of survey analysis procedures to run the Box-Cox transformation of the data, the figures of the prevalence of inadequacy, excess nutrient intake, and deficiency risk were estimated using the standard procedures of SAS Statistical Software (PROC TRANSREG, PROC MEANS, PROC GLM) with a weight statement to take into consideration the weighting factors, thus part of the representativeness of the individuals. All data management and statistical analyses were performed using SAS Software (version 9.4, SAS Institute Inc., Cary, NC, USA), except the EpiDiet model that was run on Python version 3.7.1. Significance was set at $P < 0.05$ for all statistical tests.

Results

Baseline characteristics

Among the 1365 18-to-65-year-old selected survey participants, 146 were identified as PB+ eaters. Compared to PB- eaters ($n=1219$), this chosen population was ~ 4 y younger and had a $\sim 2\text{kg/m}^2$ lower BMI (**Table 1**). No differences were found regarding sex ratio or other socio-demographic characteristics (**Supplementary Table S4**). The cut-offs (80th percentile) for plant-based energy and plant protein intakes were 70.9% of the energy intake and 41.7% of the protein intake, respectively (see **Supplementary Figure S1**). Among the PB+ eaters, 76.2 ± 0.4 % of the energy intake and 49.5 ± 0.7 % of the protein intake came from plant-based foods (Table 1). Animal and plant protein intakes in PB+ eaters were, respectively, 27 g lower and only 7 g higher than PB- eaters. On average, PB+ eaters had a lower protein intake when adjusting for energy intake. No differences were found regarding energy intake, but PB+ eaters had a lower mean energy expenditure than PB- eaters. When analysing separately males and females, the differences in BMI

were only found in PB+ females, while the lower energy expenditure was only observed in PB+ males.

After adjusting for energy intake, PB+ eaters as a whole had higher consumption of refined grains, vegetables, legumes, potatoes, seeds and nuts, sugar and sweeteners, fruit juices, and substitutes for animal products than the rest of the population (PB- eaters). They also had lower consumptions of meat (both red and processed), poultry, fish (both lean and fatty), milk and dairy products, and animal fat (**Supplementary Table S5**).

Quality of the diets

All Plant-based dietary Indices (overall, healthful and unhealthful) were significantly higher for both sexes among PB+ eaters compared with PB- eaters (Table 1). As regards scores of nutrient adequacy, the overall PANDiet score, as well as its subscores (Moderation Subscore and Adequation Subscore), were not significantly different between PB- and PB+ females. On the other hand, while no differences were observed for the Moderation Subscore in males, both the overall PANDiet and its Adequation Subscore were lower in PB+ males (Table 1), indicating a lower nutrient adequacy for PB+ males. SecDiet scores were slightly lower in PB+ subjects of all sexes and in females, but no differences were observed in males (Table 1).

Prevalence of inadequacy, excess intakes, and deficiency risk

Figures of prevalence of inadequacy were not significantly different for most of the nutrients of interest: differences were found for only 13 nutrients out of 27 (**Fig. 1**). A higher prevalence of inadequacy was observed in PB+ eaters than in PB- eaters for selenium, protein, calcium, riboflavin, vitamin B6, bioavailable iron, vitamin A, iodine, and vitamin B12. On the other hand, lower prevalence of inadequacy was determined for fibre, linoleic acid, vitamin C, and potassium. Although the same trends were observed for each sex, the differences in prevalence of inadequacy for protein, calcium, vitamin A, linoleic acid, and potassium were found significant only

in females. No increase in risk of amino acid inadequacy was found, except for very small increases for valine, lysine, and leucine in females.

The prevalence of excess protein intake was very low for both PB+ and PB- eaters, and no difference was observed between the two groups (see supplementary material). Less PB+ eaters exceeded the UL set for SFA, but more exceeded the one set for sugars (**Fig. 2**).

Regarding the prevalence of risk of overt deficiency, we found no difference between PB+ and PB- eaters, except for iodine and riboflavin, for which the prevalence was higher for PB+ eaters. When considered by sex, the differences only remained for iodine in PB+ males and riboflavin in PB+ females (**Fig. 3**).

Detailed results can be found in the supplementary material for inadequacy (**Supplementary Table S6**), excess nutrient intake (**Supplementary Table S7**), and risk of overt deficiency (**Supplementary Table S8**).

Impact of the diet on long-term health

Shifting to a PB+ diet would benefit population health, with ~132,700 [~125,400-~140,000, 95% UI] Disability-Adjusted Life Years (DALYs) averted. The gain would be higher for males than females (~92,000 vs. ~40,700 DALYs averted) and explained by a lower incidence of the same main diseases in both sexes (ischemic heart diseases, diabetes, and colorectal cancer) (**Fig. 4**). Results were similar when considering avoided deaths (**Supplementary Figure S3**).

The decreases in processed meat and SFA in the diet were among the main contributors to the benefit: the decrease in processed meat ranked first and would avert 55,346 DALYs in the French adult population, that is 32.1% of the sum of averted DALYs (42,930 DALYs corresponding to 38.5% of the sum of averted DALYs in males; 12,417 DALYs corresponding to 20.3% of averted DALYs in females). The reduced consumption of SFA would avert 17,873 DALYs in the French adult population, corresponding to 10.4% of the sum of averted DALYs (10,718 DALYs, 9.6% in males; 7155 DALYs, 11.7% in females). Other significant contributors were higher nut consumption (1st contributor) and a reduction of blood

cholesterol (3rd contributor) in females and higher fruit consumption (4th contributor) and fibre intake (3rd contributor) in males (**Table 2**). Effects of all dietary factors considered in the model on the averted DALYs and avoided deaths are presented in the whole population and by sex for each disease in **Supplementary Tables S9** (DALYs) and **Supplementary Tables S10** (deaths).

Discussion

We have assessed the nutritional risks and long-term health benefits of marginally more plant-based eaters in the adult population of a Western country. The major findings of this study are that more plant-based (PB+) eaters have a higher prevalence of inadequacy for a limited set of nutrients, with no increase in the risks of overt deficiency. On the other hand, we estimated a lower risk for long-term health, especially for males.

Adequacy of vitamins and minerals

The overall adequacy of nutrient intake was similar in PB+ and PB- eaters as assessed with the Adequacy Subscore of the PANDiet. However, since the Adequacy Subscore combines probabilities of nutrient adequacy for a large set of nutrients, similar scores can hide contrasted detail, and this was the case here. Firstly, there were some vitamins and minerals for which the intakes were very low in PB+ eaters, with a higher probability of not meeting requirements as compared to PB-. That was the case for riboflavin, vitamins B6 and B12. However, the assessment of the prevalence of insufficient intakes carries uncertainties regarding the estimates of the average requirements [44] and the criteria used to set the reference intake [45]; thus, the final impact on health of these low intakes remains insufficiently characterized. When assessing the risk of overt deficiency, we only found a higher risk in PB+ for riboflavin and iodine. Animal-based foods are rich in riboflavin, vitamin B6, and B12 [46], and low intakes of these vitamins have been reported in plant-based eaters [5]. However, in the literature, the risk of insufficient intakes of riboflavin has been mostly reported when milk and dairy are low or absent in the diet (as in vegans) [47] or in modelling studies when substituting milk and dairy

with plant-based substitutes [20]. The very low intakes of riboflavin have not been associated with a risk of overt deficiency in Western countries. The prevalence of overt deficiency, namely ariboflavinosis, is virtually null in high-income countries, and the characterized adverse health effect of milder forms of riboflavin deficiency remains uncertain. Nonetheless, riboflavin plays an important role in one-carbon metabolism, and riboflavin subdeficiency has been associated with hypertension, especially in individuals with the MTHFR 677TT genotype [48, 49]. The finding of a higher risk of iodine deficiency in this moderately plant-based population could be considered unexpected. However, in many Western countries where the iodine fortification program is insufficient [50, 51], iodine requirements are met chiefly from fish and dairy intake, and the latter is a critical contributor to iodine sufficiency, as shown in observed or modelling studies [52]. Here, the PB+ eaters consumed about half as much fish and dairy as the PB- eaters. In contrast, we are not surprised that the risk of overt deficiency in vitamin B12 was not higher in PB+ eaters since this risk has only been reported in vegans [47, 53]. However, low intakes of vitamin B12 could lead to higher levels of plasma homocysteine, as reported in lacto-ovo-vegetarians, and this may increase the risk of cardiovascular diseases [1, 8]. Lastly, we found no increase in the risks of deficiency reported in vegetarian populations such as iron, zinc, and EPA+DHA, even though our estimates, based on the bioavailable fraction for iron and zinc, are more precise and sensitive for diets higher in plants. This confirms that nutritional risks in moderately plant-forward diets cannot be inferred from data on vegetarians.

France has a low food and staple food fortification, which might explain the high prevalence of insufficient intake observed for some nutrients in the general population. This may be particularly true for people, such as the PB+ eaters, who have a lower consumption of foods that are traditional sources of nutrients.

Therefore, although very low, this nutritional risk could be avoided in PB+ eaters with food fortification or supplementation. However, since it has been reported that dietary supplementation little impacts the nutritional status of the general population

in Europe [54], supplementation should be tailored to the specific nutritional risks of the subpopulations or adequate food fortification should be implemented.

Secondly, in contrast, PB+ eaters had a lower inadequacy for fibre, linoleic acid, potassium, and vitamin C. Those levels of inadequacy were high in our overall sample, similar to what has been reported in the general population in high-income countries, although inadequacy in potassium has been rarely assessed [54–56]. These classical nutrient shortages are partly alleviated by the higher consumption of some plant food groups, which in the present study were mostly grains (and especially whole-grain cereals) and, to a lesser extent, legumes, nuts, and seeds.

Adequacy in energy macronutrients

Although small, the increase in the prevalence of protein inadequacy was unexpected because protein adequacy has been shown to be high in vegetarians and vegans when carefully assessed [57–60]. This increase appears to be due to the low level of plant protein intake in this subpopulation, which is, in fact, related to the relatively low quality of their diet compared to plant-based diets. As previously modelled, when animal protein is markedly reduced, as in a fraction of this subpopulation, an increase in plant foods that are low in protein (such as grains) may not be sufficient to fully ensure protein adequacy and a greater diversity of plant protein is needed [31, 61]. This means including higher-protein foods such as legumes and some plant-based substitutes, which was not enough the case in a small portion of this subpopulation. In contrast, since no protein food group was excluded in PB+ diet, protein diversity remains high enough so that protein sources complement each other, and the estimates of amino acid inadequacy remain virtually null or, at least, consistently lower than those of protein inadequacy [31, 57]. Only a very low protein diversity in plant dominant-diets would result in amino acid deficiencies despite a sufficient protein intake [31].

We found some changes in the risks of excess SFA and sugars but not sodium intake. Although concerns have been raised about the frequently high sodium content of plant-based substitutes [52], higher sodium intakes have not been reported for people with a more plant-based diet over the spectrum of vegetarian

diets [62]. The number of people with excessive SFA intake was approximately halved in the PB+ eaters. It has been well described in the literature that more plant-based diets are associated with much lower SFA intakes and that the intakes are very high in the general population in high-income countries [63, 64]. Meat and dairy are important contributors to SFA intakes, and PB+ eaters had about half the meat and dairy intake of PB- ones. Modelled decreases in meat and dairy have been shown to markedly decrease the excessive intake of SFA [65]. In contrast, we did not expect that PB+ eaters would have a higher prevalence of excess sugars intake. This was not readily fully explained by the higher consumption of a few food groups, such as sugary products and fruit juice. There are previous reports about diets with more plant protein being associated with lower – not higher – intakes of food groups rich in added sugars such as sugar-sweetened beverages [66, 67]. The motivation of the more plant-based eaters in our sample may be less health-related than in more classical plant-forward diets. These changes in excessive intakes have important implications for long-term health, which we could assess as part of the comparative risk assessment framework.

Hypothetical changes in the burden of diseases

We estimated that the consumption of PB+ diets by the whole French adult population would avoid 3,100 deaths, corresponding to 7 deaths for 100,000 French adults. Due to the associated incapacity from the incidence of the diseases, particularly cardiovascular diseases and diabetes, the effects on long-term health would be important, with ~132,000 averted DALYs corresponding to ~300 averted DALYs/100,000 French adults. The benefits of the PB+ dietary pattern were mostly carried by lower processed meats and higher fruit and nuts intakes. Such differences in consumption have been described as important for the beneficial effects of plant-based diets in general [68, 69]. A supplemental benefit could have been expected from the lower red meat consumption in PB+ eaters. However, our comparative risk assessment model did not include the relation between red (and processed) meat and the risk of colorectal cancer [70]. The PB+ dietary pattern was also associated with lower SFA and higher fibre intakes, which explained a large

part of the benefits. Indeed, SFA and fibre are well-known pivotal nutrients when considering the share of plant and animal sources in the diet and long-term health [71, 72].

However, the dietary pattern of PB+ eaters could have been of better quality. Indeed, adherence to a more plant-based diet in PB+ came along a higher level of both the healthy and the unhealthy dimensions of a plant-based diet, as shown by the hPDI and uPDI scores in PB+ [22]. Historical and cultural plant-based diets such as vegetarian diets consist of very healthy dietary patterns [7]. In contrast, people adhering to a more plant-based diet without this cultural background may be more likely to adopt a less healthy plant-based diet [73]. Here, PB+ eaters had higher intakes of sugars and sodium, as previously mentioned. In light of the present results, the long-term health benefits would be higher if PB+ eaters had relied more on whole grains, vegetables, and pulses and less on sugary products.

People with plant-based diets, such as vegetarians, have a lower BMI [74], and people adopting more plant-based diets have lower body mass gain [75]. In our sample, PB+ eaters had a lower BMI. We chose to assess the impact of diet adjusted for energy intake to avoid uncertainty in the assessment of energy intake and to describe the effects of the dietary pattern from a more qualitative viewpoint. However, the lower BMI of the PB+ eaters may result from a lower energy balance, which would be an additional important factor for long-term health benefits. Ultimately, we may have largely underestimated the beneficial effects of plant-based diets.

Limitations and strengths

This study has some limitations. The sample size was relatively small, but we could study around 10% of the population in a representative survey. It proved sufficient to show relevant differences in nutrient adequacy and long-term health. Another limitation is that, although it was the latest national one, the survey was conducted in 2014-2015. More recent data could have revealed more apparent trends related to the consumption of more plant-forward diets for a part of the population or

different versions of more plant-based diets. However, dietary patterns appear to have evolved slowly in the last decade [76].

The strength of this study is that it assesses plant-forward diets currently observed in a rather significant proportion of the population, which may provide a realistic benchmark for future changes in population diet. Another strength is to give a complete picture of the different types of nutritional risks and benefits, from the risk of overt deficiency to the risk to long-term health.

Conclusion

We conclude that when there are limited nutritional risks to adopting a moderate plant-based diet, but significant benefits for long-term health of the population. However, these diets are far from optimal, and better versions could be identified and promoted for nutrition and health. Finally, at this level of plant in the diet (ca. 50% of protein from plant foods [71]), a better version of the diet stands in the general food-based dietary guidelines made for the general population: increased consumptions of whole-grains, nuts, legumes and reduced consumption of red and processed meats and sugar-sweetened beverages.

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PM, FM, JFH and JMM designed research; PM and JW conducted research; PM, FM and JFH analysed data; and PM, FM and JFH wrote the paper. PM had primary responsibility for final content. All authors read and approved the final manuscript.

Data availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

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Tables

Table 1. Sociodemographic characteristics of the population of more plant-based eaters (PB+ eaters), compared to the rest of the population (designated as “less plant-based eaters or PB- eaters”).

	All			Males			Females		
	PB- eaters n = 1219	PB+ eaters n = 146	<i>P</i> ^a	PB- eaters n = 519	PB+ eaters n = 74	<i>P</i> ^a	PB- eaters n = 700	PB+ eaters n = 72	<i>P</i> ^a
Age, y	42.9 ± 0.6	39 ± 1.9	NS	42.6 ± 1	39 ± 2.3	NS	43.2 ± 0.7	39.1 ± 3.3	NS
Sex, % men	52.1	51.9	NS	-	-	-	-	-	-
BMI, kg/m ²	25.1 ± 0.2	23.2 ± 0.5	<0.001	25.2 ± 0.2	23.8 ± 0.8	NS	25.1 ± 0.3	22.5 ± 0.7	<0.001
BMI categories			0.014			NS			0.006
Overweight (25 < BMI < 30 kg/m ²), %	35.2	17.8		40.6	21.7		29.2	13.5	
Obesity (BMI > 30 kg/m ²), %	11.2	7.2		8.5	10.6		14.2	3.5	
Height, cm	169.6 ± 0.4	169.8 ± 1.1	NS	175.9 ± 0.5	175 ± 1.3	NS	162.9 ± 0.4	164.2 ± 1.0	NS
Self-declared vegetarians, %	2.1	4.6	NS	2.6	2.0	NS	1.5	7.5	<0.01
Energy intake excluding alcohol (EIEA), kcal/d	2238 ± 33	2266 ± 72	NS	2545 ± 50	2459 ± 113	NS	1904 ± 32	2057 ± 85	NS
Physical activity, MET-h/week	56.4 ± 3.8	38.1 ± 4.4	<0.01	78.7 ± 6.4	48.7 ± 6.2	<0.001	32.2 ± 2.5	26.8 ± 5.1	NS
% of EIEA from plant-based foods	62.3 ± 0.3	76.2 ± 0.4	<0.0001	62.8 ± 0.5	75.5 ± 0.5	<0.0001	61.8 ± 0.4	77 ± 0.6	<0.0001
Total protein (energy-adjusted), g/d	93.4 ± 1.1	74.1 ± 1.6	<0.0001	106.4 ± 1.4	83.5 ± 2.0	<0.0001	79.2 ± 1.1	63.9 ± 1.4	<0.0001
% of protein from plant-based foods	31.4 ± 0.4	49.5 ± 0.7	<0.0001	31.6 ± 0.6	48.6 ± 0.8	<0.0001	31.2 ± 0.4	50.4 ± 1.1	<0.0001
SCORES									
Overall PDI (oPDI) (18-90)	52.1 ± 0.2	57.6 ± 0.6	<0.0001	51.9 ± 0.3	57.0 ± 0.7	<0.0001	52.3 ± 0.3	58.4 ± 1.0	<0.0001

Healthful PDI (hPDI) (18-90)	52.3 ± 0.3	55.8 ± 0.9	<0.001	52.0 ± 0.4	54.9 ± 1.0	<0.05	52.6 ± 0.4	56.7 ± 1.6	<0.05
Unhealthful PDI (uPDI) (18-90)	55.1 ± 0.3	58.3 ± 1.0	<0.01	55.1 ± 0.4	57.3 ± 0.9	<0.05	55.0 ± 0.4	59.4 ± 1.8	<0.05
PANDiet (0-100)	68.0 ± 0.3	67.0 ± 0.6	NS	68.2 ± 0.4	65.6 ± 0.8	0.004	67.9 ± 0.3	68.5 ± 1.0	NS
Adequacy Subscore (AS) (0-100)	66.1 ± 0.6	61.9 ± 1.4	0.006	70.1 ± 0.8	63.1 ± 2.3	0.003	61.8 ± 0.8	60.7 ± 1.6	NS
Moderation Subscore (MS) (0-100)	69.9 ± 0.6	72.0 ± 1.3	NS	66.2 ± 0.9	68.0 ± 2.0	NS	73.9 ± 0.6	76.2 ± 1.7	NS
SecDiet (0-1)	0.91 ± 0.00	0.88 ± 0.01	0.017	0.93 ± 0.01	0.90 ± 0.02	NS	0.89 ± 0.01	0.85 ± 0.02	0.025

^a Categorical variables: First-order Rao-Scott chi-Square Test (design adjusted Pearson chi-square test); Continuous variables: T-test

Results are expressed as Mean ± Standard Error to the Mean for continuous variables and as percentages for categorical variables.

EIEA: Energy intake excluding alcohol; AS: Adequacy subscore / MS: Moderation subscore; hPDI: healthful Plant-based Diet Index; oPDI: overall Plant-based Diet Index; uPDI: unhealthful Plant-based Diet Index

Table 2. Estimated averted DALYs related to all diseases – effect of the main dietary factors in the context of a shift of the population’s diet from the current diet to the diet of the PB+ eaters – results are presented by sex

Factors	Amount ^a in PB+ eaters’ diet compared to current French diet	Averted DALYs			Factor ranking ^b			Factor contribution (%) ^c		
		Wh. pop.	Males	Females	Wh. pop.	Males	Females	Wh. pop.	Males	Females
		Processed meat	-	55346	42930	12417	1	1	2	32.1%
Blood cholesterol	-	22543	8679	13863	2	5	1	13.1%	7.8%	22.7%
Fibre (higher consumption)	+	21016	16966	4051	3	3	6	12.2%	15.2%	6.6%

Fruit (excluding juices)	+	19983	18119	1864	4	2	11	11.6%	16.3%	3.1%
SFA	-	17873	10718	7155	5	4	4	10.4%	9.6%	11.7%
Nuts & Seeds	+	15265	5720	9545	6	7	3	8.9%	5.1%	15.6%
Red meat	-	9067	6308	2758	7	6	8	5.3%	5.7%	4.5%

Total (all factors

included in the model, n=23)

	NA	132738	92023	40715	NA	NA	NA	NA	NA	NA
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Wh. pop.: Whole population

^a For blood cholesterol: modelled concentration based on PB+ eaters' diet consumption compared to modelled concentration based on the consumption of the current French diet

^b As highlighted by the "Wh. pop." column, the table lists the seven risk factors having the most effect on the number of averted DALYs when considering the whole population (both sexes) while 23 risk factors were included in the EpiDiet model (see supplementary tables S9 for details). This explains why factor ranks can be higher than 7 in males or females.

^c Factor contribution calculated as the percentage of the sum of averted DALYs. Since, the effects of the different factors are not additive, total averted DALYs do not correspond to the sum of averted DALYs. Consequently, the sum of DALYs do not correspond to total averted DALYs.

Figures

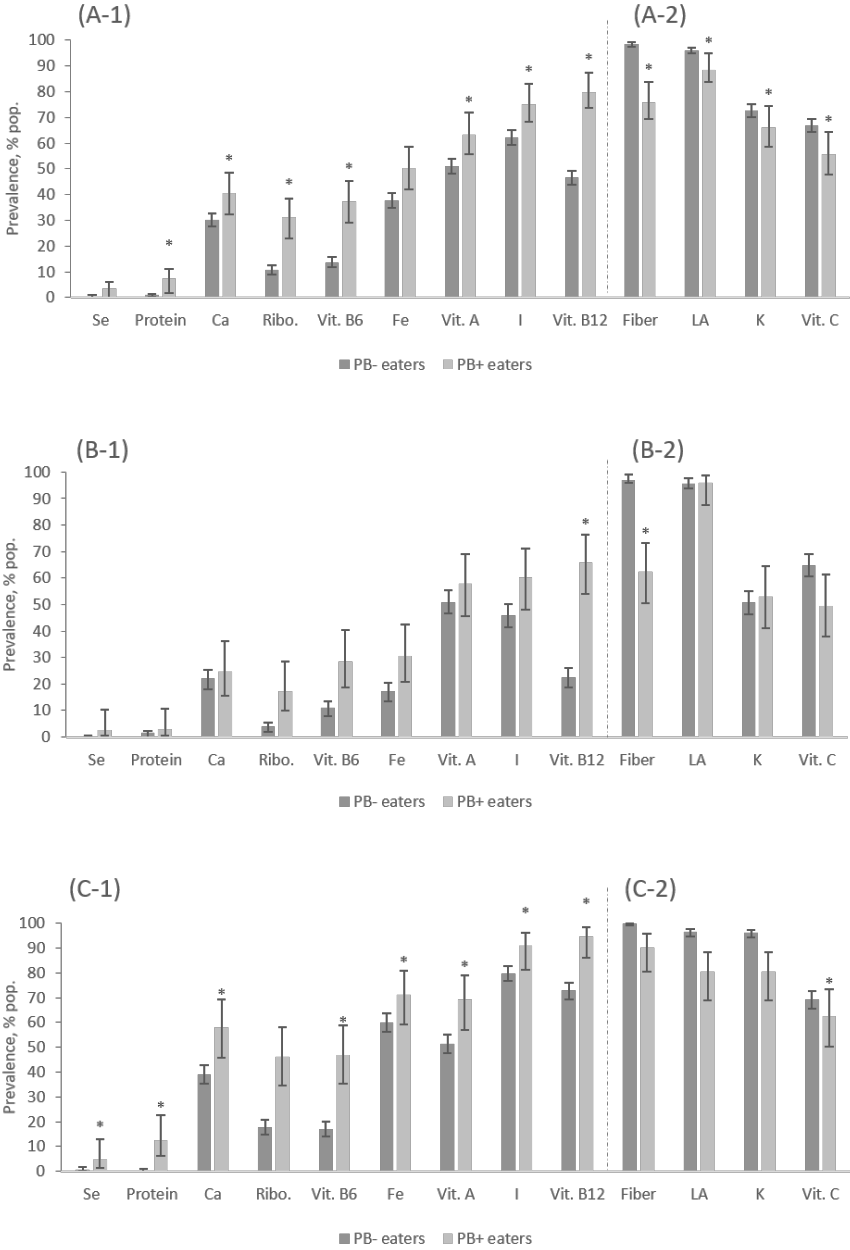


Fig. 1 Figures of prevalence of inadequacy in PB- and PB+ eaters for both sexes (A), males (B) and females (C) – only nutrients for which a significant difference was observed for both sexes are presented (i.e. non-overlapping confidence intervals). X-1 sections of the graphs display nutrients for which a higher prevalence of inadequacy was observed for PB+ eaters while X-2 sections of the graphs show nutrient for which a lower prevalence of inadequacy was observed in PB+ eaters. Error bars represent the 95% confidence intervals; stars (*) represent statistically significant differences (non-overlapping confidence intervals).
 Ca: calcium; Fe: bioavailable iron; I: iodine; K: potassium; LA: linoleic acid; Ribo.: riboflavin; Se: selenium; Thiam.: thiamine; Vit.: vitamin.

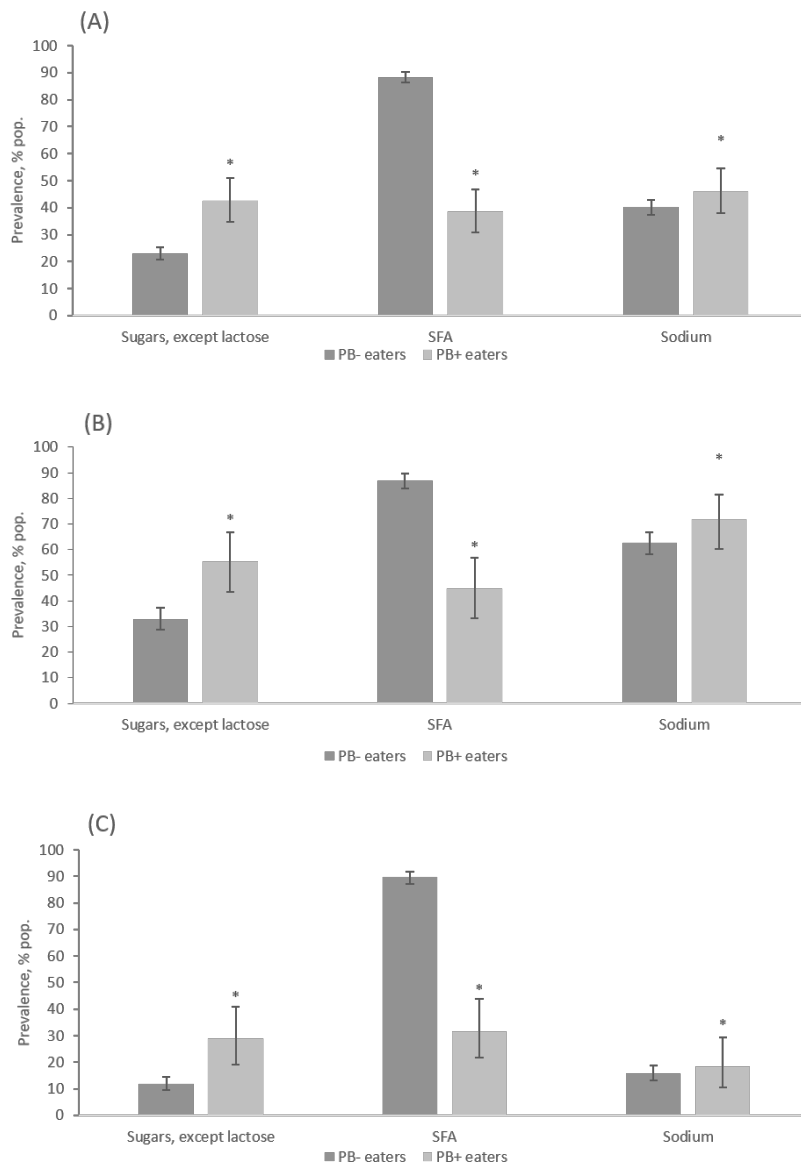


Fig. 2 Figures of prevalence of excess intake in PB- and PB+ eaters for both sexes (A), males (B) and females (C). Error bars represent the 95% confidence intervals; stars (*) represent statistically significant differences (non-overlapping confidence intervals).

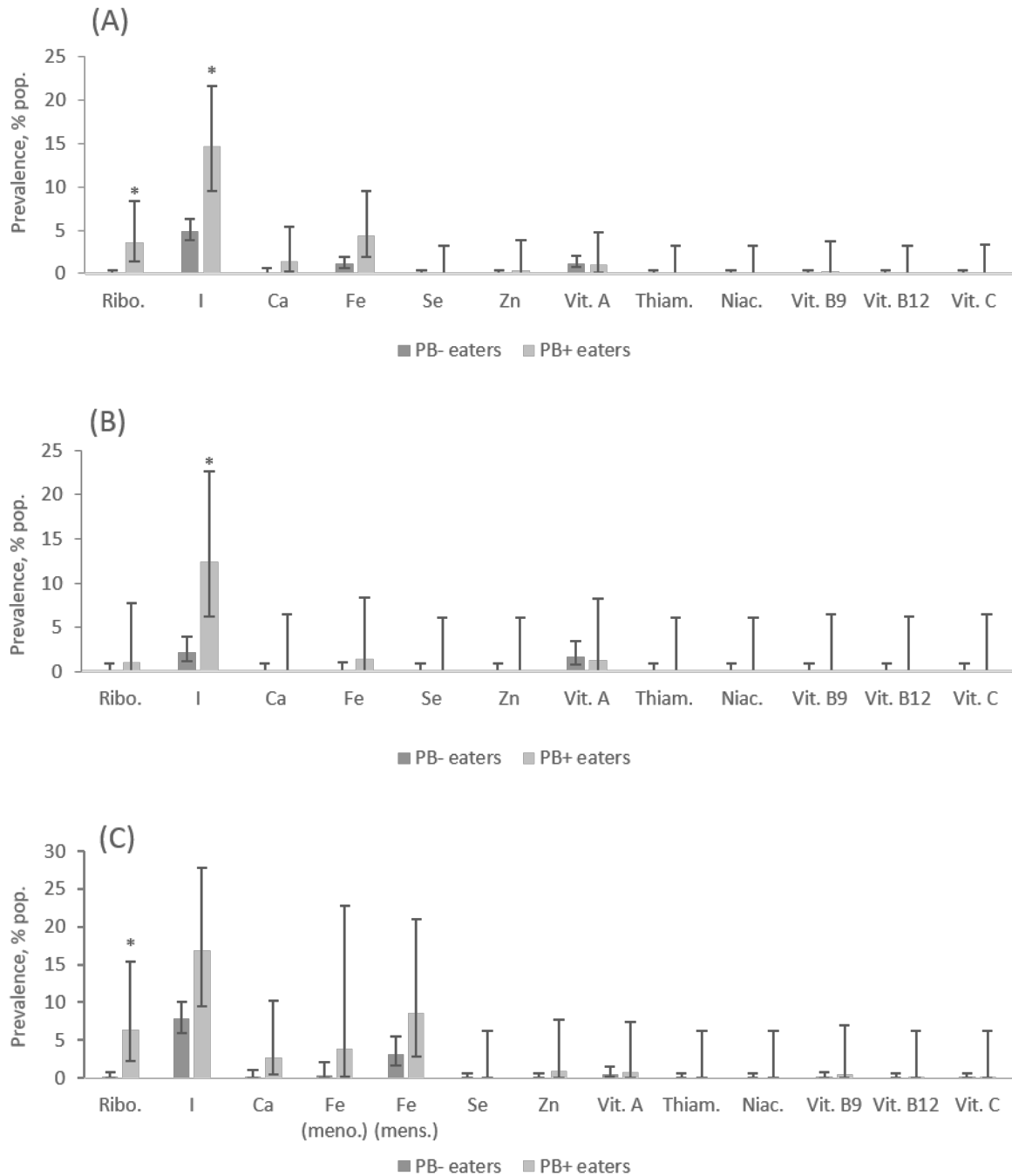


Fig. 3 Figures of prevalence of risk of overt deficiency in PB- and PB+ eaters for (A) both sexes, (B) males and (C) females. Error bars represent the 95% confidence intervals; stars (*) represent statistically significant differences (non-overlapping confidence intervals). Ca: calcium; Fe: bioavailable iron; I: iodine; meno.: menopausal; mens.: menstruating; Niac.: niacin; Ribo.: riboflavin; Se: selenium; Thiam.: thiamine; Vit.: vitamin; Zn: zinc

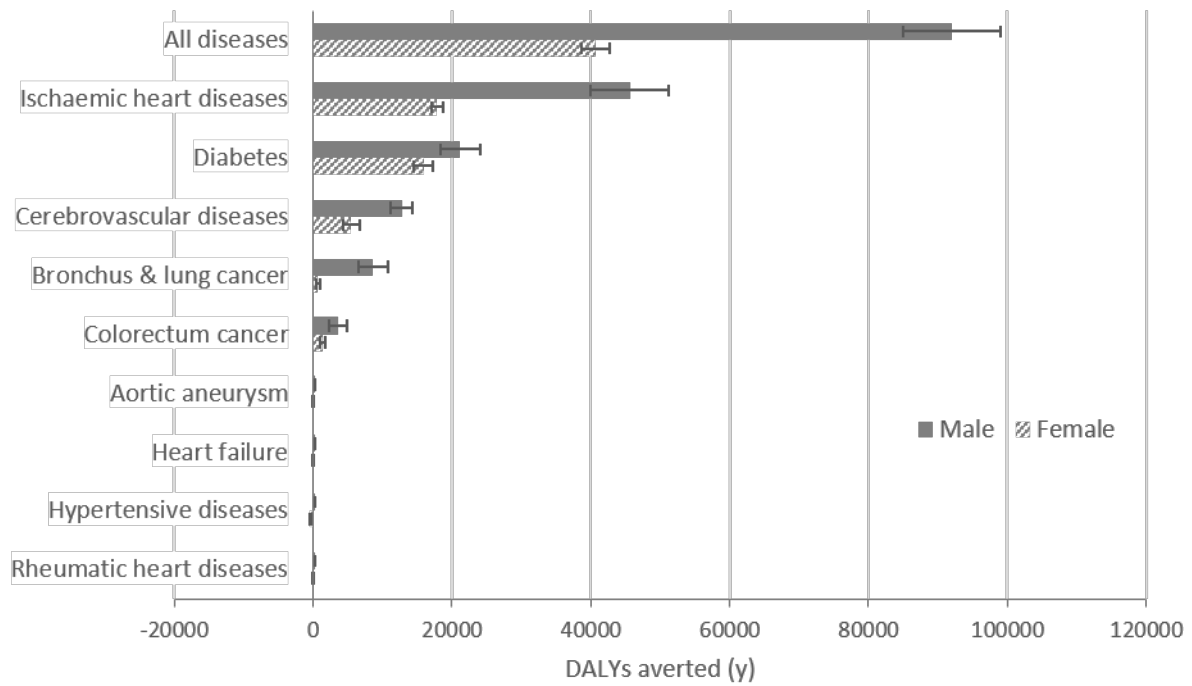
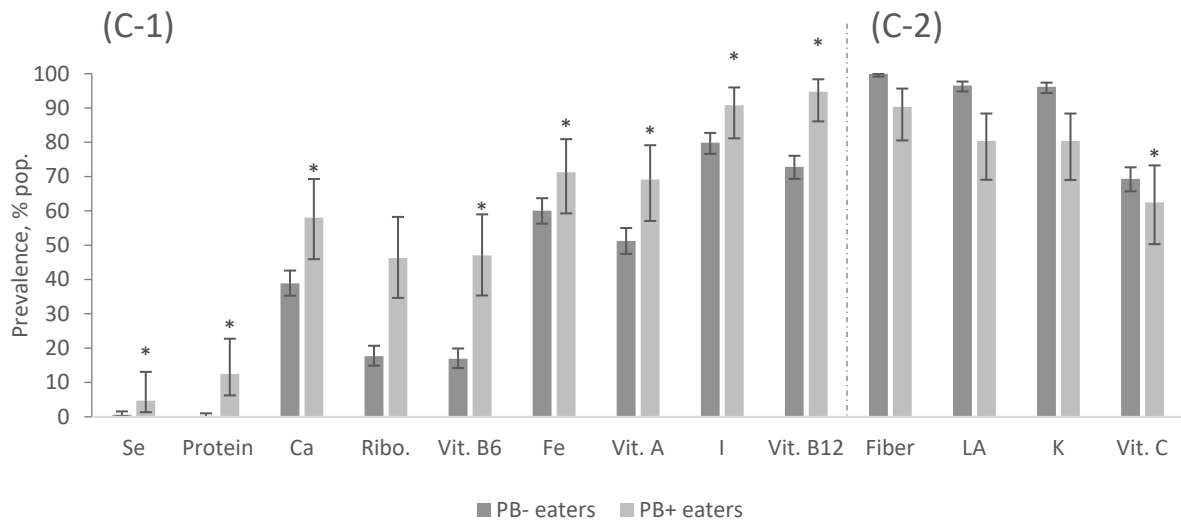
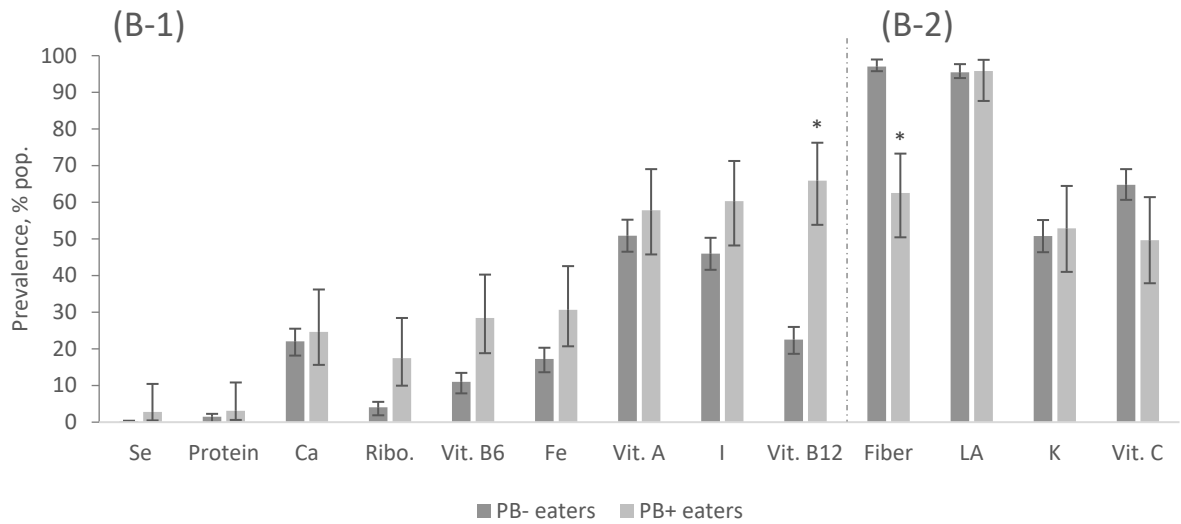
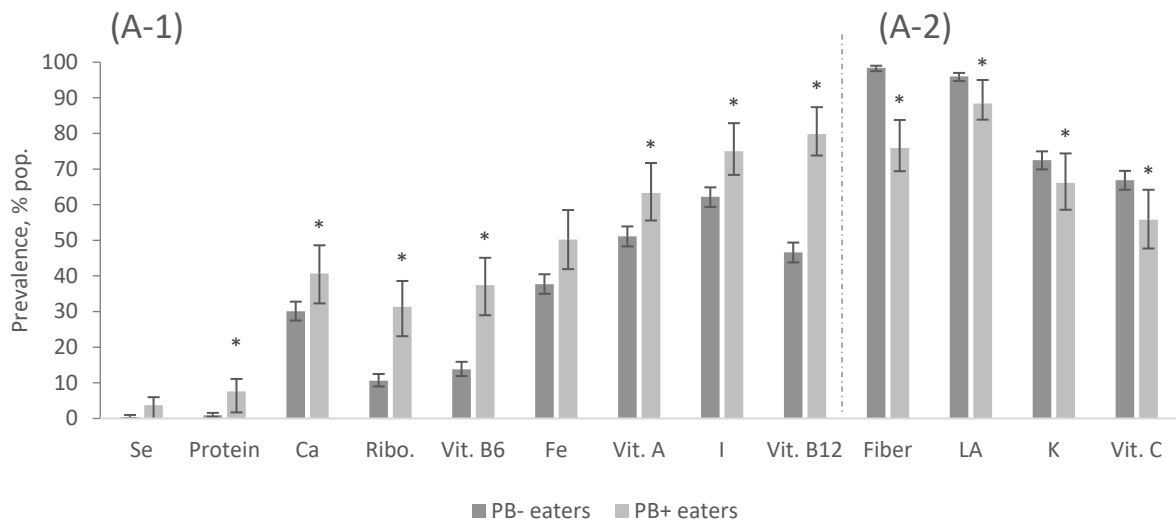
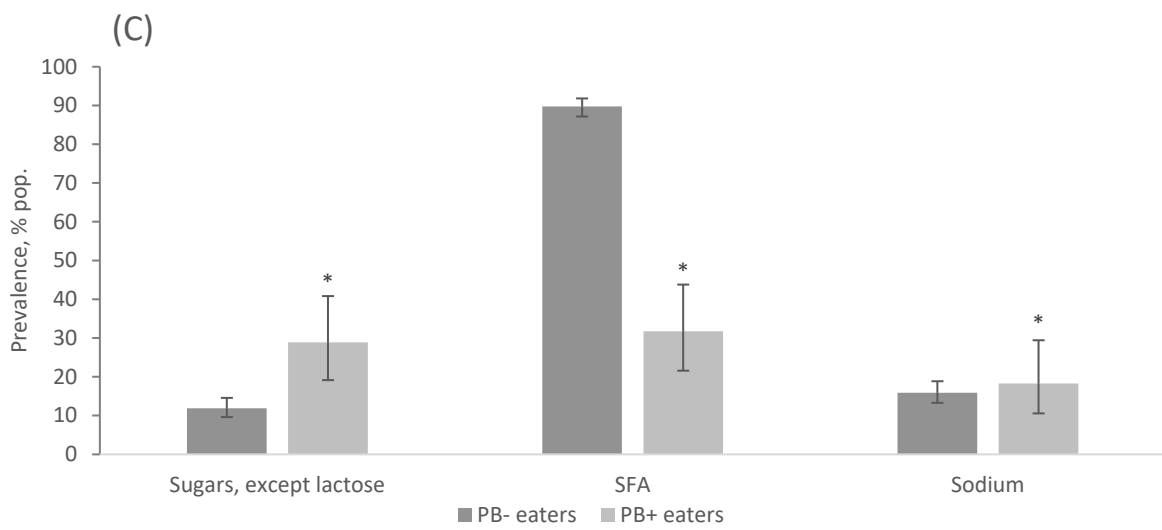
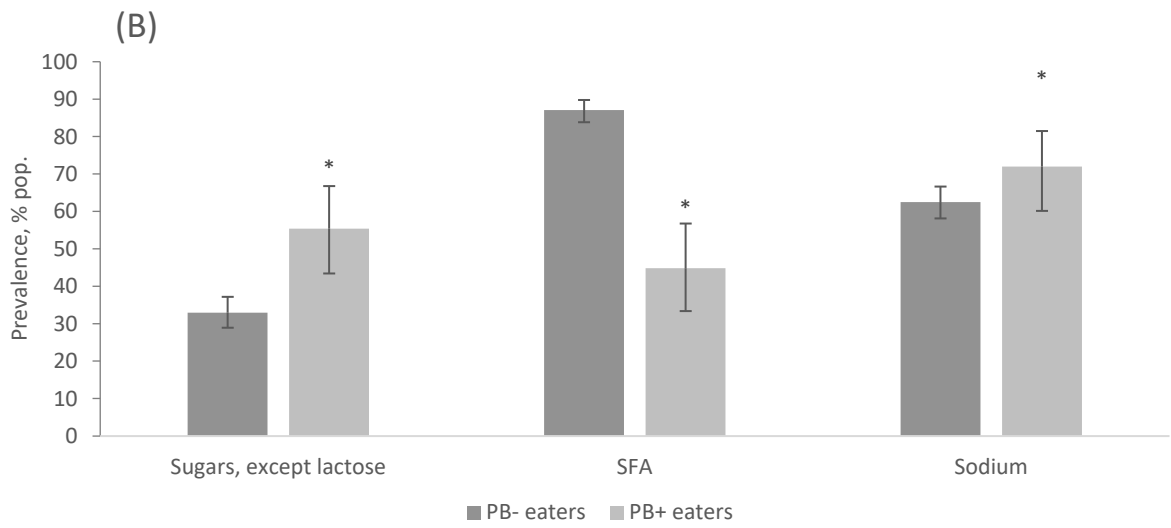
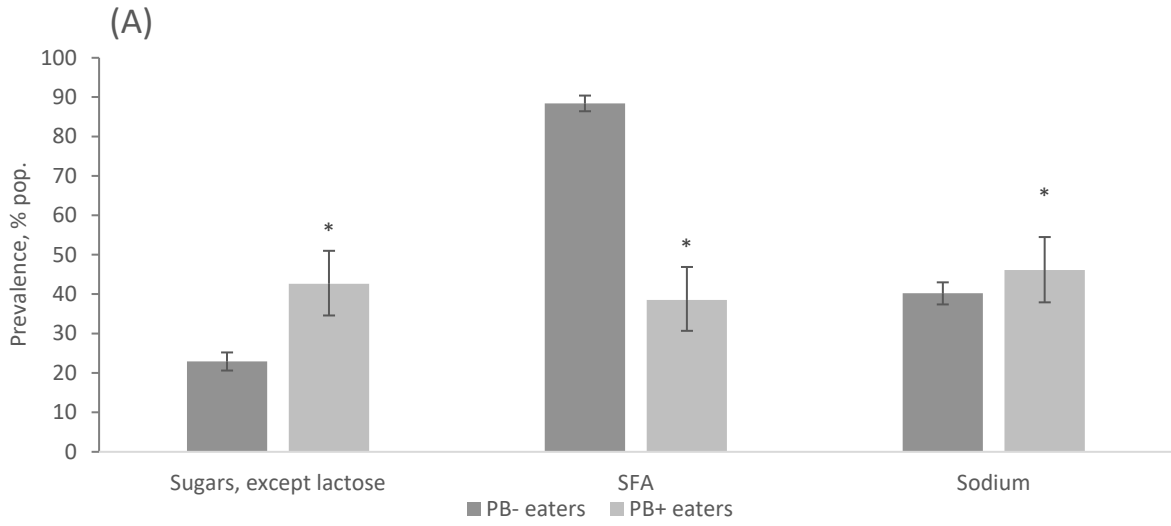
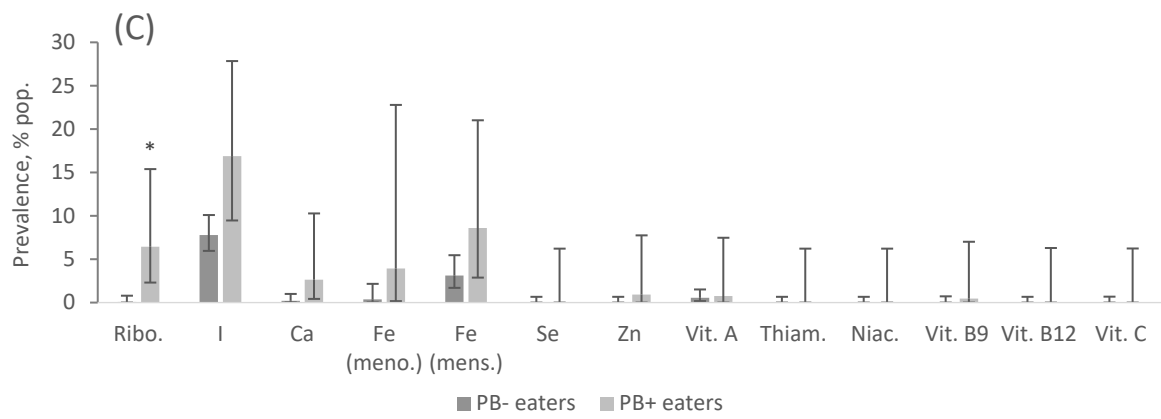
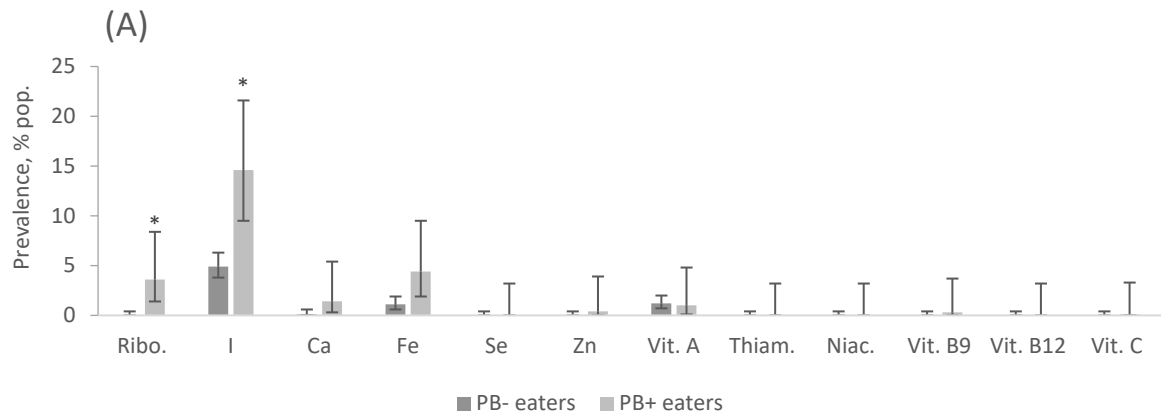
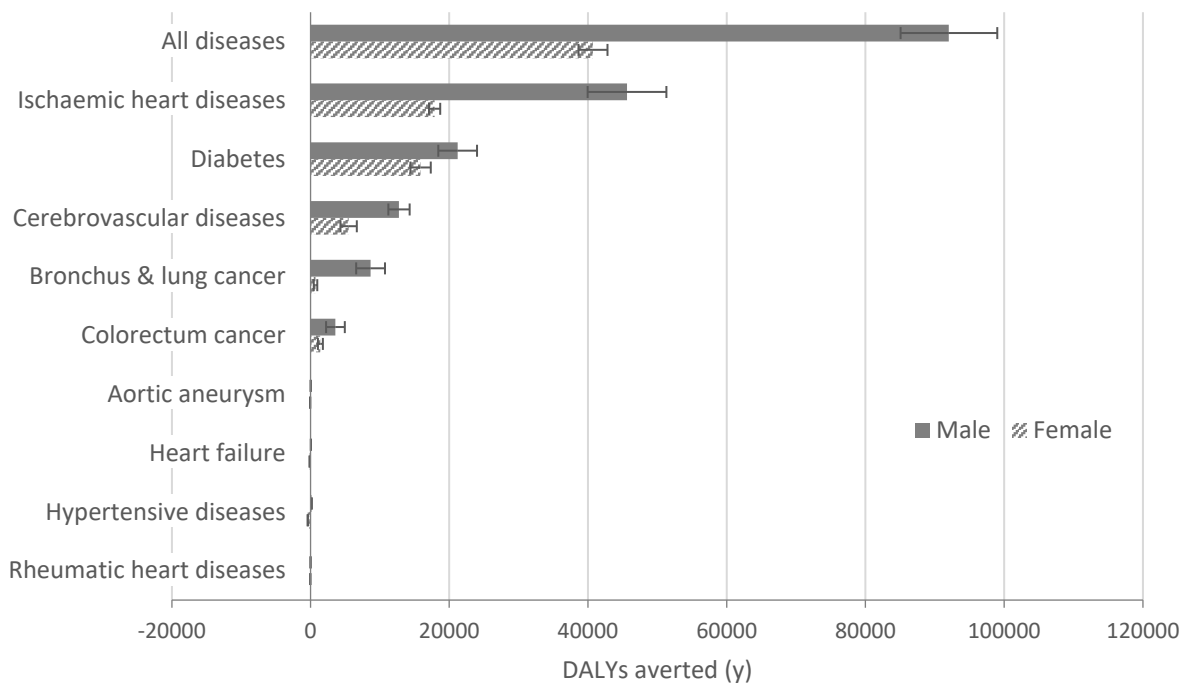


Fig. 4 Estimated DALYs averted by a shift from the current diets to the diets of the PB+ eaters, by sex. Error bars represent the 95% uncertainty intervals.









Supplementary material

Pauline Mombert¹, Jean-François Huneau¹, Juhui Wang¹, Jeanne-Marie Membré², François Mariotti^{1*}. *Limited risks of nutrient deficiency and significant modelled health benefits of adherence to a moderate plant-based diet in French adults*. European Journal of Nutrition

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Supplementary Table S1 – PANDiet index Nutrient Reference Values – version 3.2

For some nutrients, no estimated average requirement (EAR) is currently available. In such cases (except for phosphorus, dealt with differently), a “pseudo EAR” was determined, based on the adequate intake (AI) and the coefficient of variation (CV) using the following formula:

$$\text{pseudo EAR} = \frac{AI}{(1 + 2 \cdot CV)}$$

Assuming that the EAR is normally distributed in the population and that the AI has been determined so as to cover the need of 97,5% of the population thus verifying $AI = EAR + 2 \cdot \sigma \leftrightarrow AI = EAR (1 + 2 \cdot CV)$.

PANDiet score = Average of Adequacy and Moderation subscores

ADEQUACY SUBSCORE					
Nutrient	Type	Reference Value (/day)	CV	PANDiet ref. val. (/day)	Ref.
Protein	EAR	0.66 g/kg b.w.	12 %	0.66 g/kg b.w.	1
LA	PAI	4 % EIEA	15 %	3.08 % EIEA	2
ALA	PAI	1 % EIEA	15 %	0.769 % EIEA	2
DHA	PAI	0.250 g	15 %	0.192 g	2
EPA + DHA	PAI	0.500 g	15 %	0.385 g	2
Fiber	PAI	30 g	15 %	23 g	3
Vitamin A	EAR	♂: 580 µg ♀: 490 µg	15 %	♂: 580 µg ♀: 490 µg	4
Thiamin (B1)	EAR	0.3 mg/1000 kcal	20 %	0.3 mg/1000 kcal	4
Riboflavin (B2)	EAR	1.3 mg	10 %	1.3 mg	4
Niacin (B3)	EAR	5.44 mg NE/1000kcal	10 %	5.44 mg NE/1000kcal	4
Pantothenic acid (B5)	OAI	♂: 6 mg ♀: 5 mg	40 %	♂: 3.33 mg ♀: 2.78 mg	4,5
Vitamin B6	EAR	♂: 1.5 mg ♀: 1.3 mg	10 %	♂: 1.5 mg ♀: 1.3 mg	4
Folate (B9)	EAR	250 µg	15 %	250 µg	4
Vitamin B12	PAI	4 µg	10 %	3.33 µg	4
Vitamin C	EAR	90 mg	10 %	90 mg	4
Vitamin D	PAI	15 µg	25 % ^(a)	10 µg	3,4
Vitamin E	OAI	♂: 10 mg ♀: 9 mg	45 %	♂: 5.26 mg ♀: 4.74 mg	4,5
Calcium	EAR	≤ 24 y.o.: 860 mg >24 y.o.: 750 mg	≤ 24 y.o.: 15% ^(b) >24 y.o.: 13% ^(b)	≤ 24 y.o.: 860 mg >24 y.o.: 750 mg	4,6
Copper	OAI	♂: 1.9 mg ♀: 1.5 mg	60 %	♂: 0.86 mg ♀: 0.68 mg	4,5
Iodine	PAI	150 µg	20 %	107 µg	4
Bioavailable iron	EAR	See Supplementary Method 1			7,4,8
Magnesium	OAI	♂: 380 mg ♀: 300 mg	35 %	♂: 224 mg ♀: 176 mg	4,5
Manganese	OAI	♂: 3,4 mg ♀: 2,8 mg	40 %	♂: 1.89 mg ♀: 1.56 mg	3,5

Phosphorus ^(c)	PAI	$\left(\frac{I_{Ca}}{1.4}\right)$ mmol	7.5%	$I_{Ca} \cdot \left(\frac{\frac{1}{1.9} + \frac{1}{1.4}}{2}\right)$ mmol	4,7,9
Potassium	PAI	3500 mg	15 %	2692 mg	4
Selenium	PAI	70 µg	15 %	54 µg	4
Bioavailable zinc	EAR	0.642 + 0.038 b.w.	10 %	0.642 + 0.038 b.w.	10

MODERATION SUBSCORE				
Nutrient	Type	Reference value (/day)	CV	Ref.
Protein	UL	2.2 g/kg b.w.	12 %	3
Total fat ^(d)	UL	44 % EIEA	5 %	3,11
SFA	UL	12% EIEA	15 %	2
Carbohydrates ^(d)	UL	60.5 % EIEA	5 %	3,11
Sugars, except lactose ^(e)	UL	100 g	15 %	12
Sodium ^(f)	UL	3200 mg	14 %	4,13,14

PENALTIES				
Nutrient	Type	Reference value (/day)	CV	Ref.
Vitamin A	UL	3000 µg	N/A	4
Niacin (B3)	UL	900 mg	N/A	4
Vitamin B6	UL	25 mg	N/A	4
Folate (B9)	UL	1150 µg	N/A	4
Vitamin D	UL	100 µg	N/A	4
Calcium	UL	2500 mg	N/A	4
Copper	UL	5 mg	N/A	4
Iodine	UL	600 µg	N/A	4
Dissociable magnesium	UL	250 mg	N/A	4
Selenium	UL	300 µg	N/A	4
Zinc ^(g)	UL	25 mg	N/A	4

ALA: α-linolenic acid; b.w.: body weight; CV: coefficient of variation; DHA: docosahexaenoic acid; EAR: Estimated Average Requirement; EIEA: energy intake excluding alcohol; EPA: eicosapentaenoic acid; LA: linoleic acid; NE: niacin equivalent; OAI: “Observational” Adequate Intake (i.e. AI derived from intake observed in a healthy population); PAI: “Physiological” Adequate Intake (i.e. AI derived from physiological criteria); UL: Tolerable Upper Intake Limit.

♂: male-specific

♀: female-specific

(a): The value of the coefficient of variation is not clearly mentioned in Anses’ opinions. However, it can be recalculated based on the EAR (10 µg/d) and RDA (15 µg/d) proposed in 2016³, assuming a normal distribution of vitamin D

requirements ($RDA = EAR (1 + 2 \times CV) \Leftrightarrow CV = \frac{\left(\frac{RDA}{EAR} - 1\right)}{2}$).

(b): As proposed by de Gavelle *et al.*⁷, the coefficient of variation of 13% set for individuals over 24 y.o. was calculated using the EAR and the RDA estimated from balances studies by EFSA⁶. In the absence of specific data, a default CV of 15% was used for young adults (18-24 y.o.).

(c): For adults, Anses⁴ decided to endorse the dietary reference value proposed by EFSA⁹. The value was derived based on the DRV for calcium, considering that the molar calcium to phosphorus ratio ranges from 1.4:1 to 1.9:1 and selecting the lower bound of this range (1.4:1, which results in a higher phosphorus intake value). As proposed by De Gavelle *et al.*⁷, the reference value for PANDiet was calculated considering that a molar ratio of 1.4:1 would correspond to an adequate intake for 97.5% of the population (which is what has been done by EFSA) while a molar ratio of 1.9:1 would correspond to an adequate intake for 2.5% of the population. Thus, considering a normal distribution, the pseudo EAR for phosphorus can be calculated as the mean of $\left(\frac{I_{Ca}}{1.4}\right)$ and $\left(\frac{I_{Ca}}{1.9}\right)$, i.e.

$$\text{Pseudo EAR}_P = I_{Ca} \cdot \left(\frac{1}{1.9} + \frac{1}{1.4} \right) \cdot \frac{1}{2}, \text{ with } I_{Ca} \text{ the calcium intake, expressed in mmol.}$$

With the same assumptions, the coefficient of variation CV_P is calculated:

$$CV_P = \left(\frac{1}{\frac{1}{1.9} + \frac{1}{1.4}} \cdot \frac{1}{1.4} \right) - \frac{1}{2} \approx 7.5\%.$$

(d): As proposed by De Gavelle *et al.*¹¹, the reference value for total fat and carbohydrates were updated to ensure a 97.5% probability of adequacy for the upper limit of the confidence interval set by Anses³ ([35%-40%] and [40%-55%], respectively), considering a small coefficient of variation of 5%.

(e): The upper limit of 100 g/d is set for sugars, except lactose and galactose. In the absence of available data on the amount of galactose in food items, the upper limit was applied to sugars, except lactose.

(f): From a literature review, the HMD determined that for a sodium intake between 2300 mg/d and 4100 mg/d, any reduction in the intake would reduce the chronic disease risk¹³. Thus, as proposed by Salomé *et al.*¹⁴, the upper limit for sodium intake was determined hypothesizing that respectively, 2.5% and 97,5% of the population would be at higher risk of chronic disease with sodium intakes of 2300 mg/d and 4100 mg/d. When considering the lower bound of this interval (i.e. 2300 mg/day) as the UL, almost all individuals have a probability of 1 of being at risk of excess intake. Thus, to better discriminate between individuals having intakes slightly or severely above the UL, we used as cut-off value the intake at which 50% of the population would be at higher risk of chronic disease. We derived this value as well as the associated standard deviation and coefficient of variation considering a normal distribution: $\mu = \frac{2300 + 4100}{2} \Leftrightarrow \mu = 3200 \text{ mg/d}$,

$$\sigma = \frac{4100 - 2300}{4} \text{ and } CV = \frac{\sigma}{\mu} \Leftrightarrow CV = \frac{\frac{4100 - 2300}{4}}{\frac{2300 + 4100}{2}} \Leftrightarrow CV \approx 14\%.$$

(g): Unlike when setting the EAR, zinc bioavailability was not considered when setting the Tolerable Upper Intake Limit.

Supplementary Table S2 – SecDiet index Nutrient Reference Values

Nutrient	Type	Reference Value (/day)	CV	SecDiet ref. val. (/day)	Ref.
Vitamin A	DT	♂: 300 µg ♀: 270 µg	15%	♂: 230.8 µg ♀: 207.7 µg	15
Thiamin (B1)	EAR	0.3 mg/1000 kcal	20%	0.13 mg/1000 kcal	4
Riboflavin (B2)	EAR	1.3 mg	10%	0.87 mg	4
Niacin (B3)	EAR	5.44 mg NE/1000 kcal	10%	3.63 mg NE/1000 kcal	4
Folate (B9)	EAR	250 µg	15%	134.6 µg	4
Vitamin B12	DT	1 µg	15%	0.77 µg	16
Vitamin C	DT	10 mg	10%	8.33 mg	17
Calcium	DT	500 mg	15%	384.6 mg	16,18
Iodine ^(a)	DT	150/1.13 = 132.7 µg	20%	94.8 µg	4,19,20
Bioavailable iron	EAR	See <i>Supplementary Method 1</i>			7,4,8,18
Selenium	DT	♂: 21 µg ♀: 16 µg	15%	♂: 16.2 µg ♀: 12.3 µg	21
Bioavailable zinc ^(b)	DT	♂: 2.0 mg ♀: 1.7 mg	15%	♂: 1.54 mg ♀: 1.31 mg	18,22

CV: Coefficient of Variability; DT: Deficiency Threshold; EAR: Estimated Average Requirement; NE: Niacin Equivalent

♂: male-specific reference value

♀: female-specific reference value

((^a): For iodine, the adequate intake of 150 µg estimated for adults⁴ was taken as a deficiency threshold, with a CV of 20%. However, this threshold tends to overestimate the risk of overt deficiency. Consequently, a correction factor based on the national prevalence of goitre (ca. 12.8% in France¹⁹) has been applied so as to readjust the estimation of the risk of deficiency to obtain a prevalence of inadequacy of $12.8 \cdot 5 = 7.8\%$ in 18-to-65-year-old adults of the French national representative survey INCA3. The deduction of 5% accounts for the fact that a cut-off value of 5% has been set to signal the presence of iodine-related public health problem since “*goitre may occur in iodine-replete populations because of the presence of goitrogens in the diet and autoimmune thyroid diseases*”²⁰. In other words, it can be assumed that around 5% of the goitre observed in the French adult population are not related to iodine deficiency.

(b): For zinc, requirements were estimated using a factorial approach, as proposed by Salomé *et al.*¹⁸ (see supplemental method 1). The same values were considered for urinary and sweat losses (♂: 0.63 mg/d; ♀: 0.44 mg/d), integumental losses (♂: 0.54 mg/d; ♀: 0.46 mg/d), losses in semen (0.1 mg/g) and menstrual losses (0.1 mg/g). Losses from the intestine were re-evaluated to 0.7 mg/d: based on the relationship between absorbed and excreted zinc established by the Institute of Medicine²², we selected the amount of absorbed zinc corresponding to an equilibrium between absorption and intestinal excretion (intersect between the regression line of intestinal endogenous losses and that of equality between endogenous and absorbed zinc ($y = x$)).

Supplementary Table S3 – Methods and cut-off points used to estimate prevalence of inadequacy, excess nutrient intake and risk of overt deficiency

PREVALENCE of INADEQUACY						
Nutrient	Type	Nutrient Reference value (/day)	CV	Method	If applicable, cut-point value	Ref.
Protein	EAR	0.66 g/kg b.w.	12 %	Probabilistic	NA	1
Histidine	EAR	10 mg/kg/day	12 %	Probabilistic	NA	1
Isoleucine	EAR	20 mg/kg/day	12 %	Probabilistic	NA	1
Leucine	EAR	39 mg/kg/day	12 %	Probabilistic	NA	1
Lysine	EAR	30 mg/kg/day	12 %	Probabilistic	NA	1
Aromatic amino acids (Phe + Tyr)	EAR	25 mg/kg/day	12 %	Probabilistic	NA	1
Threonine	EAR	15 mg/kg/day	12 %	Probabilistic	NA	1
Thryptophan	EAR	4 mg/kg/day	12 %	Probabilistic	NA	1
Valine	EAR	26 mg/kg/day	12 %	Probabilistic	NA	1
Sulphur amino acids (Met + Cys)	EAR	15 mg/kg/day	12 %	Probabilistic	NA	1
LA	PAI	4 % EIEA	15 %	Cut-point	4 % EIEA	2
ALA	PAI	1 % EIEA	15 %	Cut-point	1 % EIEA	2
DHA	PAI	0.250 g	15 %	Cut-point	0.250 g	2
EPA + DHA	PAI	0.500 g	15 %	Cut-point	0.500 g	2
Fiber	PAI	30 g	15 %	Cut-point	30 g	3
Vitamin A	EAR	♂: 580 µg ♀: 490 µg	15 %	Probabilistic	NA	4
Thiamin (B1)	EAR	0.3 mg/1000 kcal	20 %	Probabilistic	NA	4
Riboflavin (B2)	EAR	1.3 mg	10 %	Probabilistic	NA	4
Niacin (B3)	EAR	5.44 mg NE/1000 kcal	10 %	Probabilistic	NA	4
Pantothenic acid (B5)	OAI	♂: 6 mg ♀: 5 mg	40 %	Cut-point	♂: 2.65 mg ♀: 2.10 mg	4,5
Vitamin B6	EAR	♂: 1.5 mg ♀: 1.3 mg	10 %	Probabilistic	NA	4
Folate (B9)	EAR	250 µg	15 %	Probabilistic	NA	4
Vitamin B12	PAI	4 µg	10 %	Cut-point	4 µg	4
Vitamin C	EAR	90 mg	10 %	Probabilistic	NA	4
Vitamin D	PAI	15 µg	25 % ^(a)	Cut-point	15 µg	3,4
Vitamin E	OAI	♂: 10 mg ♀: 9 mg	45 %	Cut-point	♂: 3.12 mg ♀: 2.22 mg	4,5
Calcium	EAR	≤ 24 y.o.: 860 mg >24 y.o.: 750 mg	≤ 24 y.o.: 15 % ^(b) >24 y.o.: 13 % ^(b)	Probabilistic	NA	4,6
Copper	OAI	♂: 1.9 mg ♀: 1.5 mg	60 %	Cut-point	♂: 0.79 mg ♀: 0.53 mg	4,5
Iodine	PAI	150 µg	20 %	Cut-point	150 µg	4
Bioavailable iron	EAR			See Supplementary Method 1		7,4,8

Magnesium	OAI	♂: 380 mg ♀: 300 mg	35 %	Cut-point	♂: 180.9 mg ♀: 137.7 mg	4,5
Manganese	OAI	♂: 3,4 mg ♀: 2,8 mg	40 %	Cut-point	♂: 1.32 mg ♀: 0.98 mg	3,5
Phosphorus	PAI	550 mg	7.5 %	Cut-point	550	4
Potassium	PAI	3500 mg	15 %	Cut-point	3500 mg	4
Selenium	PAI	70 µg	15 %	Cut-point	70 µg	4
Bioavailable zinc	EAR	♂: 0.642 + 0.038 x 78.6 ^(c) ♀: 0.642 + 0.038 x 65.5 ^(c)	10 %	Probabilistic	NA	10

PREVALENCE of EXCESS INTAKE

Nutrient	Type	Nutrient Reference value (/day)	CV	Method	If applicable, cut-point value	Ref.
Protein	UL	2.2 g/kg b.w.	12 %	Cut-point	2.2 g/kg b.w.	3
SFA	UL	12% EIEA	15 %	Cut-point	12% EIEA	2
Sugars, except lactose ^(d)	UL	100 g	15 %	Cut-point	100 g	12
Sodium ^(e)	UL	3200 mg	14 %	Cut-point	3200 mg	4,13,14

PREVALENCE of RISK of OVERT DEFICIENCY

Nutrient	Type	Nutrient Reference value (/day)	CV	Method	If applicable, cut-point value	Ref.
Vitamin A	DT	♂: 300 µg ♀: 270 µg	15 %	Cut-point	♂: 230.8 µg ♀: 207.7 µg	15
Thiamin (B1)	EAR	0.3 mg/1000 kcal	20 %	Cut-point	0.13 mg/1000 kcal	4
Riboflavin (B2)	EAR	1.3 mg	10 %	Cut-point	0.87 mg	4
Niacin (B3)	EAR	5.44 mg NE/1000 kcal	10 %	Cut-point	3.63 mg NE/1000 kcal	4
Folate (B9)	EAR	250 µg	15 %	Cut-point	134.6 µg	4
Vitamin B12	DT	1 µg	15%	Cut-point	0.83 µg	16
Vitamin C	DT	10 mg	10 %	Cut-point	8.33 mg	17
Calcium	DT	500 mg	15 %	Cut-point	384.6 mg	16,18
Iodine^(f)	DT	150/1.13 = 132.7 µg	20 %	Cut-point	94.8 µg	4,19,20
Bioavailable iron	EAR	<i>See Supplementary Method 1</i>				7,4,8,18
Selenium	DT	♂: 21 µg ♀: 16 µg	15 %	Cut-point	♂: 16.2 µg ♀: 12.3µg	21
Bioavailable zinc^(g)	DT	♂: 2.0 mg ♀: 1.7 mg	15%	Cut-point	♂: 1.54 mg ♀: 1.31 mg	18,22

ALA: α-linolenic acid / CV: coefficient of variation / DHA: docosahexaenoic acid / DT: Deficiency Threshold / eDT: estimated Deficiency Threshold / EAR: Estimated Average Requirement / EIEA: energy intake excluding alcohol / EPA: eicosapentaenoic acid / LA: linoleic acid / NE: niacin equivalent / OAI: Observed Adequate Intake / PAI: Physiologically-based Adequate Intake / SFA: saturated fatty acids / UL: Tolerable Upper Intake Level

♂: male-specific
♀: female-specific

(a): The value of the coefficient of variation is not clearly mentioned in Anses' opinions. However, it can be recalculated based on the EAR (10 µg/d) and RDA (15 µg/d) proposed in 20163, assuming a normal distribution of vitamin D requirements ($RDA = EAR (1 + 2 \times CV)$ ⇒ $CV = \frac{(RDA - EAR)}{2 \times EAR}$).

(b): As proposed by de Gavelle *et al.*⁷, the coefficient of variation of 13% set for individuals over 24 y.o. was calculated using the EAR and the RDA estimated from balances studies by EFSA⁶. In the absence of specific data, a default CV of 15% was used for young adults (18-24 y.o.).

(c): To estimate the reference value for zinc, we used the equation for physiological zinc requirements proposed by EFSA¹⁰, considering the mean weights in males (78.6 kg) and females (65.5) (18-to-65 year-old individuals, excluding under-reporters).

(d): The upper limit of 100 g/d is set for sugars, except lactose and galactose. In the absence of available data on the amount of galactose in food items, the upper limit was applied to sugars, except lactose.

(e): From a literature review, the HMD determined that for a sodium intake between 2300 mg/d and 4100 mg/d, any reduction in the intake would reduce the chronic disease risk¹³. Thus, as proposed by Salomé *et al.*¹⁴, the upper limit for sodium intake was determined hypothesizing that respectively, 2.5% and 97.5% of the population would be at higher risk of chronic disease with sodium intakes of 2300 mg/d and 4100 mg/d. When considering the lower bound of this interval (i.e. 2300 mg/day) as the UL, almost all individuals have a probability of 1 of being at risk of excess intake. Thus, to better discriminate between individuals having intakes slightly or severely above the UL, we used as cut-off value the intake at which 50% of the population would be at higher risk of chronic disease. We derived this value as well as the associated standard deviation and coefficient of variation considering a normal distribution: $\mu = \frac{2300 + 4100}{2} \Leftrightarrow \mu = 3200 \text{ mg/d}$,

$$\sigma = \frac{4100 - 2300}{4} \text{ and } CV = \frac{\sigma}{\mu} \Leftrightarrow CV = \frac{\frac{4100 - 2300}{4}}{\frac{2300 + 4100}{2}} \Leftrightarrow CV \approx 14\%.$$

(f): For iodine, the adequate intake of 150 μg estimated for adults⁴ was taken as a deficiency threshold, with a CV of 20%. However, this threshold tends to overestimate the risk of overt deficiency. Consequently, a correction factor based on the national prevalence of goitre (ca. 12.8% in France¹⁹) has been applied so as to readjust the estimation of the risk of deficiency to obtain a prevalence of inadequacy of $12.8 - 5 = 7.8\%$ in 18-to-65-year-old adults of the French national representative survey INCA3. The deduction of 5% accounts for the fact that a cut-off value of 5% has been set to signal the presence of iodine-related public health problem since “*goitre may occur in iodine-replete populations because of the presence of goitrogens in the diet and autoimmune thyroid diseases*”²⁰. In other words, it can be assumed that around 5% of the goitre observed in the French adult population are not related to iodine deficiency.

Bioavailable zinc⁽⁸⁾: For zinc, requirements were estimated using a factorial approach, as proposed by Salomé *et al.*¹⁸ (see supplemental method 1). The same values were considered for urinary and sweat losses (σ^2 : 0.63 mg/d; σ^- : 0.44 mg/d), integumental losses (σ^2 : 0.54 mg/d; σ^- : 0.46 mg/d), losses in semen (0.1 mg/g) and menstrual losses (0.1 mg/g). Losses from the intestine were re-evaluated to 0.7 mg/d: based on the relationship between absorbed and excreted zinc established by the Institute of Medicine²², we selected the amount of absorbed zinc corresponding to an equilibrium between absorption and intestinal excretion (intersect between the regression line of intestinal endogenous losses and that of equality between endogenous and absorbed zinc ($y = x$)).

Supplementary Table S4 – Socio-demographic characteristics in PB- and PB+ eaters included in the study

	All (n=1365)			Males (n=593)			Females (n=772)		
	PB- eaters (n=1219)	PB+ eaters (n=147)	<i>p</i> ¹	PB- eaters (n=519)	PB+ eaters (n=74)	<i>p</i> ¹	PB+ eaters (n=700)	PB- eaters (n=72)	<i>p</i> ¹
Sex, % females	57.71	51.81	NS						
Age Group, %			NS			NS			NS
18-24 y.o.	7.29	8.81		8.54	8.6		6.38	9	
25-34 y.o.	16.32	17.62		16.09	20.43		16.49	15	
35-44 y.o.	22.57	19.69		21.84	15.05		23.1	24	
45-54 y.o.	24.1	30.05		23.65	34.41		24.43	26	
55-65 y.o.	29.72	23.83		29.89	21.51		29.6	26	
<i>Age (years), mean ± SD</i>	42.8 ± 13.6	39.2 ± 14	<0.001	42.8 ± 15.6	38.1 ± 14.1	<0.01	42.8 ± 11.9	40.5 ± 14	NS
<i>Self-declared vegetarian status, %</i>			0.011			NS			0.027
Missing data	3.4	3.63		2.79	4.3		3.85	3	
No	95.21	91.71		96.06	92.47		94.58	91	
Yes	1.39	4.66		1.15	3.23		1.56	6	
Administrative Region, %			0.01			NS			NS
Ile-de-France (Paris Region)	12.99	18.13		14.12	15.05		12.15	21	
North-West	23.19	17.1		21.35	16.13		24.55	18	
North-East	24.65	18.65		26.44	17.2		23.35	20	
South-East	20.76	28.5		19.87	31.18		21.42	26	
South-West	18.4	17.62		18.23	20.43		18.53	15	
Size of Urban Area, %			NS			NS			NS
Rural	26.81	22.28		27.59	20.43		26.23	24	
2,000-19,999 inhab.	19.1	19.69		17.57	17.2		20.22	22	
20,000-99,999 inhab.	12.92	12.44		12.15	13.98		13.48	11	
>=100,000 inhab.	29.72	29.53		29.89	33.33		29.6	26	

	All (n=1365)			Males (n=593)			Females (n=772)		
	PB- eaters (n=1219)	PB+ eaters (n=147)	<i>p</i> ¹	PB- eaters (n=519)	PB+ eaters (n=74)	<i>p</i> ¹	PB+ eaters (n=700)	PB- eaters (n=72)	<i>p</i> ¹
Paris urban area	11.46	16.06		12.81	15.05		10.47	17	
Season of the 24h recalls, %			0.029			NS			NS
Winter	25.35	21.24		25.29	24.73		25.39	18	
Spring	36.18	38.34		35.96	36.56		36.34	40	
Summer	22.5	30.05		23.65	31.18		21.66	29	
Autumn	15.97	10.36		15.11	7.53		16.61	13	
Matrimonial status, %			0.042			NS			NS
Single	22.5	29.53		26.44	34.41		19.61	25	
Married	44.17	35.75		44.66	30.11		43.8	41	
Unmarried couple	17.22	19.69		16.58	20.43		17.69	19	
Widowed	3.19	1.04		0.66	0		5.05	2	
Separated/Divorced	12.92	13.99		11.66	15.05		13.84	13	
Occupational status, %			NS			NS			NS
Office worker	20.42	15.54		11.33	6.45		27.08	24	
Manual worker	12.08	10.36		18.88	17.2		7.1	4	
Farmer	0.97	0.52		1.31	1.08		0.72	0	
Craftsman, shopkeeper or company director/owner	3.19	5.18		4.27	6.45		2.41	4	
Intermediate profession	23.4	30.57		19.21	29.03		26.47	32	
Executive, self-employed	15.97	19.17		20.69	24.73		12.52	14	
Retired	13.54	9.33		15.76	7.53		11.91	11	
Other non-working	10.42	9.33		8.54	7.53		11.79	11	
Level of Education, %			<0.01			0.03			NS
Primary & middle school	33.89	22.8		37.11	23.66		31.53	22	
High school	22.15	18.65		22	19.35		22.26	18	
1 to 3 years of post-secondary education	22.22	29.53		18.88	29.03		24.67	30	
+4 years of post-secondary education	21.67	29.02		21.84	27.96		21.54	30	

	All (n=1365)			Males (n=593)			Females (n=772)		
	PB- eaters (n=1219)	PB+ eaters (n=147)	<i>p</i> ¹	PB- eaters (n=519)	PB+ eaters (n=74)	<i>p</i> ¹	PB+ eaters (n=700)	PB- eaters (n=72)	<i>p</i> ¹
Income per Consumption Unit, %									
Not specified	0.07	0		0.16	0		0	0	
Missing data	7.15	7.77	NS	6.73	7.53	NS	7.46	8	NS
< 900 €/month/CU	18.89	17.1		16.26	17.2		20.82	17	
≤ 900-1340 < €/month/CU	19.58	21.24		18.72	19.35		20.22	23	
≤ 1340-1850 < €/month/CU	22.15	21.76		22	19.35		22.26	24	
≥ to 1850 €/month/CU	32.22	32.12		36.29	36.56		29.24	28	
Perceived Financial Situation, %			NS			NS			NS
Comfortable, content	14.79	16.06		17.08	16.13		13.12	16	
It's OK	36.67	37.31		38.42	34.41		35.38	40	
It's tight	11.53	12.44		12.15	11.83		11.07	13	
Manageable if careful	28.75	22.8		24.96	27.96		31.53	18	
Hard to make ends meet	6.88	9.33		5.91	7.53		7.58	11	
Can't manage without debts	1.39	2.07		1.48	2.15		1.32	2	
Food insufficiency, %			NS			NS			NS
Food sufficiency	82.29	86.01		84.4	88.17		80.75	84	
Qualitative food insufficiency	14.93	11.92		12.81	10.75		16.49	13	
Quantitative food insufficiency	2.78	2.07		2.79	1.08		2.77	3	
Food insecurity, %			<0.001			0.027			NS
Food security	90.9	93.78		93.1	95.7		89.29	92	
Moderate food insecurity	5.56	2.07		4.6	0		6.26	4	
Severe food insecurity	3.54	4.15		2.3	4.3		4.45	4	
BMI categories, %			<0.001			NS			<0.001
Underweight (BMI < 18.5)	2.36	5.7		1.31	2.15		3.13	9	
Normal weight (18.5 < BMI < 25)	49.24	61.14		44.01	54.84		53.07	67	
Overweight (25 < BMI < 30)	33.47	22.28		40.39	31.18		28.4	14	

	All (n=1365)			Males (n=593)			Females (n=772)		
	PB- eaters (n=1219)	PB+ eaters (n=147)	<i>p</i> ¹	PB- eaters (n=519)	PB+ eaters (n=74)	<i>p</i> ¹	PB+ eaters (n=700)	PB- eaters (n=72)	<i>p</i> ¹
Obesity (BMI > 30)	14.93	10.88		14.29	11.83		15.4	10	
<i>BMI (kg/m²), Mean ± SD</i>	25.1 ± 0.2	23.2 ± 0.5	<0.001	25.2 ± 0.2	23.8 ± 0.8	NS	25.1 ± 0.3	22.5 ± 0.7	<0.001
<i>Menopausal females, %</i>									NS
Missing data							4.33	3	
Yes							38.63	33	
No							54.87	63	
Does not know							2.17	1	

¹ Rao-Scott chi-Square test for categorial variables, T test for continuous variables, α=0.05

inhab.: inhabitants; y.o.: years old

Supplementary Table S5 – Consumption of foods groups in PB- and PB+ eaters – adjusted for energy

Food groups	All (n=1365)			Males (n=593)			Females (n=772)		
	Mean ± SD		P ¹	Mean ± SD		P ¹	Mean ± SD		P ¹
	PB- eaters (n=1219)	PB+ eaters (n=147)		PB- eaters (n=519)	PB+ eaters (n=74)		PB- eaters (n=700)	PB+ eaters (n=72)	
Refined breads	92.99 ± 72.01	135.3 ± 94.8	<0.0001	121.04 ± 81.83	165.55 ± 101.91	<0.001	72.42 ± 55.53	107.17 ± 78.23	<0.0001
Whole-grain breads	15.11 ± 31.51	22.57 ± 41.78	NS	14.37 ± 33.28	20.38 ± 42.36	NS	15.65 ± 30.15	24.6 ± 41.35	NS
Breakfast cereals & cereal bars	5.11 ± 15.73	7.19 ± 17.19	<0.001	5.2 ± 16.36	7.21 ± 15.04	<0.01	5.04 ± 15.26	7.16 ± 19.05	NS
Refined cereals	70.12 ± 73.82	94.53 ± 109.42	<0.01	84.94 ± 85.51	111.16 ± 118.39	<0.05	59.27 ± 61.74	79.08 ± 98.46	NS
Whole-grain cereals	2.51 ± 6.98	3.13 ± 7.06	NS	3.07 ± 8.49	4.76 ± 8.96	<0.05	2.1 ± 5.59	1.62 ± 4.14	NS
Biscuits & pastries	56.68 ± 51.73	57.91 ± 51.99	NS	62.93 ± 56.89	57.67 ± 53.03	NS	52.1 ± 47.1	58.14 ± 51.27	NS
Milks	72.74 ± 141.42	41.07 ± 84.75	<0.05	77.61 ± 142.18	46.65 ± 98.42	NS	69.17 ± 140.84	35.89 ± 69.79	<0.05
Yoghurts	92.69 ± 99.65	50.14 ± 63.29	<0.0001	85.61 ± 97.89	48.94 ± 58.5	<0.001	97.88 ± 100.66	51.26 ± 67.72	<0.0001
Cheeses	34.65 ± 29.62	27.34 ± 24.93	<0.01	42.03 ± 34.24	32.08 ± 26.47	<0.05	29.24 ± 24.35	22.94 ± 22.67	<0.01
Cream desserts	17.82 ± 35.35	12.97 ± 30.11	NS	20.06 ± 37.6	14.36 ± 36.52	NS	16.18 ± 33.54	11.68 ± 22.69	NS
Ice creams	5.15 ± 13.52	4.87 ± 10.57	NS	6.23 ± 15.38	5.7 ± 10.82	NS	4.36 ± 11.92	4.09 ± 10.33	NS
Animal fats	9.22 ± 12.97	5.1 ± 6.86	<0.0001	9.23 ± 12.21	5.8 ± 7.75	<0.05	9.21 ± 13.5	4.44 ± 5.88	<0.001
Vegetable fats	8.93 ± 9.32	10.42 ± 11.7	NS	9.67 ± 9.97	12.55 ± 13.63	<0.05	8.4 ± 8.78	8.44 ± 9.21	NS
Eggs	15.85 ± 30.2	10.57 ± 25.64	NS	16.36 ± 31.82	13.99 ± 34	NS	15.47 ± 28.98	7.4 ± 13.39	NS
Meat (excl. poultry)	52.43 ± 57.89	22.08 ± 29.37	<0.0001	64.42 ± 68.62	27.96 ± 34.46	<0.0001	43.65 ± 46.68	16.62 ± 22.52	<0.0001
Poultry	31.34 ± 44.17	14.49 ± 23.1	<0.0001	33.84 ± 47.32	16.35 ± 26.8	<0.001	29.51 ± 41.64	12.77 ± 19.01	<0.001
Delicatessen	35.66 ± 38.86	15.47 ± 19.9	<0.0001	44.63 ± 45.33	19.69 ± 23.66	<0.0001	29.08 ± 31.8	11.55 ± 14.68	<0.0001
Fatty fish	9.47 ± 24	3.06 ± 10.06	<0.01	10.11 ± 25.14	2.22 ± 6.71	<0.05	9 ± 23.14	3.85 ± 12.37	NS
Lean fish	19.05 ± 35.71	10.51 ± 21.77	<0.05	21.18 ± 40.9	11.18 ± 23.47	NS	17.5 ± 31.31	9.89 ± 20.15	NS
Crustaceans & molluscs	3.5 ± 14.73	3.1 ± 14.68	NS	3.87 ± 17.07	3.11 ± 18.5	NS	3.23 ± 12.75	3.09 ± 9.97	NS
Offals	2.48 ± 10.96	0.86 ± 5.44	NS	3.16 ± 12.7	1.57 ± 7.58	NS	1.99 ± 9.45	0.21 ± 1.73	NS
Vegetables	165.57 ± 140.56	197.33 ± 181.55	<0.05	172.27 ± 157.11	202.16 ± 199.58	NS	160.67 ± 126.94	192.84 ± 163.92	NS

Food groups	All (n=1365)			Males (n=593)			Females (n=772)		
	Mean ± SD		P ¹	Mean ± SD		P ¹	Mean ± SD		P ¹
	PB- eaters (n=1219)	PB+ eaters (n=147)		PB- eaters (n=519)	PB+ eaters (n=74)		PB- eaters (n=700)	PB+ eaters (n=72)	
Legumes	6.32 ± 19.91	11.36 ± 39.89	<0.05	7.82 ± 25.19	16.23 ± 52.95	<0.05	5.22 ± 14.81	6.83 ± 20.91	NS
Potatoes & tubers	42.06 ± 59.28	31.15 ± 50.72	<0.01	55.54 ± 69.58	42.32 ± 61.8	NS	32.18 ± 48.12	20.75 ± 34.83	<0.05
Dry & fresh fruits	138.9 ± 146.38	153.44 ± 138.98	NS	141.15 ± 158.79	158.99 ± 145.43	NS	137.26 ± 136.63	148.27 ± 133.23	NS
Fruit purees & fruits in syrup	15.52 ± 45.15	13.55 ± 28.64	NS	11.2 ± 40.72	10.4 ± 24.5	NS	18.69 ± 47.92	16.49 ± 31.87	NS
Seeds & nuts	2.36 ± 6.96	5.74 ± 11.58	<0.0001	3.05 ± 8.71	4.98 ± 11.87	<0.05	1.85 ± 5.29	6.45 ± 11.32	<0.0001
Sweets & chocolates	9.73 ± 20.31	10.88 ± 16.31	<0.05	11.78 ± 24.23	11.68 ± 18.57	NS	8.22 ± 16.72	10.15 ± 13.94	<0.05
Sugar & sweeteners	17.33 ± 18.96	25.78 ± 26.96	<0.0001	20.3 ± 20.9	30.62 ± 29.9	<0.01	15.15 ± 17.08	21.29 ± 23.15	<0.05
Bottled water	478.99 ± 700.22	431.38 ± 722.41	NS	505.51 ± 733.37	447.37 ± 782.69	NS	459.56 ± 674.67	416.52 ± 665.12	NS
Tap water	564.92 ± 704.21	565.73 ± 647.91	NS	602.73 ± 752.22	636.37 ± 640.84	NS	537.22 ± 665.93	500.03 ± 650.72	NS
CNAB	101.34 ± 220.72	117.14 ± 255.51	NS	123.84 ± 227.15	142.86 ± 264.1	NS	84.86 ± 214.54	93.21 ± 246.15	NS
Fruit juices	66.22 ± 99.91	96.2 ± 142.9	<0.01	73.55 ± 111.83	99.98 ± 156.87	NS	60.84 ± 89.87	92.69 ± 129.27	<0.01
Alcoholic beverages	139.4 ± 300.86	127.16 ± 206.85	NS	222.32 ± 422.02	181.53 ± 263.29	NS	78.64 ± 133.14	76.6 ± 114.91	NS
Hot beverages	572.45 ± 469.84	547.85 ± 519.33	NS	520.97 ± 446.26	493.53 ± 485.24	NS	610.17 ± 483.18	598.36 ± 546.72	NS
Soups & broths	96.46 ± 188.86	76.51 ± 162.55	NS	87.62 ± 181.75	68.15 ± 147.46	NS	102.95 ± 193.76	84.28 ± 175.81	NS
Meat dishes	12.24 ± 36.61	10.36 ± 28.38	NS	15.22 ± 45.5	12.56 ± 32.77	NS	10.06 ± 28.21	8.31 ± 23.57	NS
Fish dishes	6.55 ± 25.85	5.98 ± 17.59	NS	7.64 ± 30.46	2.64 ± 11.78	NS	5.75 ± 21.86	9.08 ± 21.23	<0.01
Vegetable dishes	15.14 ± 51.86	14.57 ± 43.42	NS	16.33 ± 61.75	13.22 ± 37.6	NS	14.27 ± 43.22	15.82 ± 48.36	NS
Potato, cereal or pulse dishes	38.03 ± 68.86	31.53 ± 57.43	NS	41.3 ± 74.76	37.2 ± 62.02	NS	35.64 ± 64.13	26.25 ± 52.56	NS
Sandwiches, pizzas, pies	33.8 ± 61.21	45.3 ± 82.24	NS	40.94 ± 72.15	58.46 ± 102.09	NS	28.56 ± 51.16	33.07 ± 55.84	NS
Condiments, herbs, spices & sauces	29.78 ± 30.75	32.79 ± 35.03	NS	34.75 ± 35.28	41.66 ± 43.45	NS	26.14 ± 26.4	24.55 ± 21.99	NS
Substitutes for animal products	5.71 ± 34.24	18.38 ± 72.33	<0.0001	3.78 ± 35.82	17.95 ± 90.12	<0.05	7.13 ± 32.98	18.78 ± 50.97	<0.0001

¹ T test, $\alpha = 0.05$

NS: Not significant (P > 0.05)

Supplementary Table S6 – Prevalence of inadequacy in PB- and PB+ eaters

Nutrient	Both Sexes			Males			Females		
	PB- eaters	PB+ eaters	*	PB- eaters	PB+ eaters	*	PB- eaters	PB+ eaters	*
Protein	0.9 (0.5-1.6)	7.6 (4.1-13.5)	*	1.5 (0.7-3.1)	3.1 (0.6-10.8)		0.2 (0-1)	12.5 (6.2-22.8)	*
Histidine	0 (0-0.4)	0.2 (0-3.6)		0 (0-0.9)	0 (0-6.2)		0 (0-0.7)	0.4 (0-7)	
Isoleucine	0 (0-0.4)	1 (0.1-4.8)		0 (0-1)	0.2 (0.1-6.5)		0 (0-0.7)	1.8 (0.2-9.1)	
Leucine	0.1 (0-0.5)	2.1 (0.5-6.4)	*	0.1 (0-1.1)	0.5 (0-7)		0 (0-0.7)	3.7 (0.9-11.8)	*
Lysine	0 (0-0.5)	2.9 (1-7.5)	*	0.1 (0-1)	1 (0-7.7)		0 (0-0.7)	5 (1.5-13.5)	*
Threonine	0 (0-0.4)	0.3 (0-3.7)		0 (0-0.9)	0.1 (0-6.3)		0 (0-0.7)	0.6 (0-7.2)	
Tryptophan	0 (0-0.4)	0 (0-3.2)		0 (0-0.9)	0 (0-6.2)		0 (0-0.7)	0.1 (0-6.4)	
Valine	0.1 (0-0.5)	1.9 (0.5-6.1)		0.1 (0-1.1)	0.5 (0-6.9)		0 (0-0.7)	3.4 (0.7-11.4)	*
Phenylalanine + Tyrosine (aromatic amino acids)	0 (0-0.4)	0 (0-3.3)		0 (0-0.9)	0 (0-6.2)		0 (0-0.7)	0.1 (0-6.4)	
Methionine + Cysteine (sulphur amino acids)	0 (0-0.4)	0.5 (0-4.1)		0 (0-0.9)	0.1 (0.1-6.4)		0 (0-0.7)	1 (0-7.8)	
Fiber	98.4 (97.5-99)	75.9 (68-82.4)	*	97 (95-98.2)	62.5 (50.4-73.3)	*	99.9 (99.2-100)	90.3 (80.6-95.7)	*
α-linolenic acid	100 (99.6-100)	99.8 (96.5-100)		100 (99.1-100)	100 (93.8-100)		100 (99.3-100)	99.7 (93.2-100)	
Linoleic acid	96 (94.7-97)	88.4 (81.8-92.9)	*	95.4 (93.2-97)	95.8 (87.6-98.9)		96.5 (94.8-97.7)	80.4 (69.1-88.4)	*
DHA	100 (99.6-100)	99.1 (95.3-99.9)		100 (99-100)	98.5 (91.5-99.9)		100 (99.3-100)	99.7 (93.3-100)	
EPA + DHA	100 (99.6-100)	99.6 (96.2-100)		100 (99.1-100)	99.3 (92.7-100)		100 (99.3-100)	99.9 (93.6-99.9)	
Vitamin A	51.1 (48.2-53.9)	63.3 (54.9-71)	*	50.9 (46.5-55.3)	57.8 (45.8-69)		51.3 (47.5-55)	69.2 (57.1-79.2)	*
Thiamin	0.2 (0-0.7)	1.1 (0.2-5)		0.3 (0-1.4)	1.3 (0.1-8.3)		0.2 (0-0.9)	0.9 (0-7.8)	
Riboflavin	10.6 (8.9-12.5)	31.3 (24.1-39.6)	*	4.1 (2.6-6.2)	17.5 (10-28.4)	*	17.7 (14.9-20.7)	46.2 (34.6-58.2)	*
Niacin	0 (0-0.4)	0 (0.1-3.2)		0 (0-0.9)	0 (0-6.1)		0 (0-0.7)	0 (0-6.2)	
Pantothenic acid	0 (0-0.4)	0.1 (0-3.3)		0 (0-0.9)	0.1 (0.1-6.4)		0 (0-0.7)	0 (0-6.3)	
Vitamin B6	13.8 (11.9-15.9)	37.4 (29.6-45.8)	*	11 (8.5-14.1)	28.4 (18.8-40.3)	*	16.9 (14.2-19.9)	47 (35.4-59)	*
Folate (B9)	23.7 (21.3-26.2)	18.7 (12.9-26.1)		13.3 (10.5-16.5)	11.6 (5.7-21.7)		35 (31.5-38.7)	26.3 (17-38.1)	
Vitamin B12	46.6 (43.8-49.5)	79.8 (72.2-85.8)	*	22.5 (19.1-26.4)	65.9 (53.9-76.3)	*	72.9 (69.4-76.1)	94.7 (86.1-98.3)	*
Vitamin C	66.9 (64.2-69.6)	55.8 (47.4-63.9)	*	64.8 (60.4-68.8)	49.6 (37.9-61.4)		69.3 (65.7-72.7)	62.5 (50.3-73.3)	

Nutrient	Both Sexes		Males		Females	
	PB- eaters	PB+ eaters	PB- eaters	PB+ eaters	PB- eaters	PB+ eaters
Vitamin D	100 (99.6-100)	100 (96.8-100)	100 (99.1-100)	100 (93.9-100)	100 (99.3-100)	100 (93.8-100)
Vitamin E	0 (0-0.4)	0 (0.1-3.2)	0 (0-0.9)	0 (0-6.2)	0 (0-0.7)	0 (0-6.2)
Calcium	30.1 (27.6-32.8)	40.7 (32.8-49.1)				
Calcium (<= 24 y.o.)			25.8 (14.3-41.5)	49.5 (13.7-85.8)	68 (51.1-81.5)	60.6 (22.5-90)
Calcium (> 24 y.o.)			21.5 (17.9-25.5)	18.8 (10.7-30.5)	36.2 (32.6-40)	57.2 (44.4-69.1) *
Copper	0 (0-0.4)	0 (0-3.2)	0 (0-0.9)	0.1 (0-6.3)	0 (0-0.7)	0 (0-6.2)
Bioavailable iron	37.7 (35-40.5)	50.2 (41.9-58.5) *	17.2 (14.1-20.8)	30.6 (20.7-42.6)		
menopausal females			NA	NA	35.8 (30.4-41.5)	46.4 (26.6-67.3)
menstruating females			NA	NA	72.8 (68.1-77.1)	77.4 (62.8-87.6)
Iodine	62.2 (59.4-64.9)	75 (67-81.6) *	46 (41.6-50.4)	60.3 (48.2-71.3)	79.9 (76.6-82.7)	90.8 (81.1-96)
Magnesium	0 (0-0.4)	0 (0-3.2)	0 (0-0.9)	0.1 (0-6.3)	0 (0-0.7)	0 (0-6.2)
Manganese	0 (0-0.4)	0 (0.1-3.2)	0 (0-0.9)	0 (0-6.2)	0 (0-0.7)	0 (0-6.2)
Phosphorus	0 (0-0.4)	1.1 (0.1-4.9)	0 (0-0.9)	0.2 (0.1-6.4)	0 (0-0.7)	2.1 (0.3-9.5)
Potassium	72.5 (69.9-75)	66.1 (57.8-73.6)	50.8 (46.4-55.1)	52.9 (41-64.5)	96.1 (94.3-97.4)	80.3 (69.1-88.4) *
Selenium	0.4 (0.1-1)	3.7 (1.4-8.6) *	0.2 (0-1.3)	2.8 (0.5-10.4)	0.6 (0.2-1.6)	4.7 (1.4-13.1)
Zinc	53.5 (50.6-56.3)	60.6 (52.2-68.5)	53.1 (48.7-57.4)	58.5 (46.5-69.7)	53.9 (50.1-57.7)	62.9 (50.7-73.7)

NA: Not Applicable

Prevalences of inadequacy among PB- and PB+ eaters for both sexes, males and females. Results are presented as estimated prevalence (% of individuals in the population of interest) with a 95% confidence interval. Stars (*) represent statistically significant differences (non-overlapping confidence intervals).

Supplementary Table S7 – Prevalence of excess intake in PB- and PB+ eaters

Nutrient	Both Sexes		Males			Females	
	PB- eaters	PB+ eaters	PB- eaters	PB+ eaters	PB- eaters	PB+ eaters	
Protein	0.2 (0-0.7)	0.4 (0-3.8)	0.4 (0.1-1.5)	0 (0-6.2)	0 (0-0.7)	0.8 (0-7.6)	
SFA	88.4 (86.4-90.1)	38.5 (30.7-46.9) *	87.1 (83.8-89.8)	44.8 (33.4-56.8) *	89.7 (87.2-91.8)	31.7 (21.6-43.8) *	
Sodium	40.2 (37.4-43)	46.1 (38-54.5)	62.5 (58.2-66.6)	72 (60.1-81.5)	15.9 (13.3-18.9)	18.3 (10.6-29.4)	
Sugars, except lactose	22.9 (20.5-25.3)	42.6 (34.6-51.1) *	32.9 (28.9-37.2)	55.4 (43.4-66.8) *	11.9 (9.6-14.6)	28.9 (19.2-40.8) *	

Prevalences of excess intake in PB- and PB+ eaters for both sexes, males and females. Results are presented as estimated prevalence with a 95% confidence interval. Stars represent statistically significant differences (non-overlapping confidence intervals).

Supplementary Table S8 – Prevalence of risk of overt deficiency in PB- and PB+ eaters

Nutrient	Both Sexes		Males		Females	
	PB- eaters	PB+ eaters	PB- eaters	PB+ eaters	PB- eaters	PB+ eaters
Vitamin A	1.2 (0.7-2)	1 (0.1-4.9)	1.7 (0.8-3.4)	1.3 (0.1-8.2)	0.5 (0.2-1.5)	0.8 (0-7.5)
Thiamin	0 (0-0.4)	0 (0-3.2)	0 (0-0.9)	0 (0-6.1)	0 (0-0.7)	0 (0-6.2)
Riboflavin	0 (0-0.5)	3.6 (1.4-8.5)	0 (0-0.9)	1 (0-7.8)	0.1 (0-0.8)	6.4 (2.3-15.4)
Niacin	0 (0-0.4)	0 (0-3.2)	0 (0-0.9)	0 (0-6.1)	0 (0-0.7)	0 (0-6.2)
Folate (B9)	0 (0-0.4)	0.3 (0-3.8)	0 (0-0.9)	0.2 (0-6.5)	0 (0-0.7)	0.5 (0-7)
Vitamin B12	0 (0-0.4)	0 (0-3.3)	0 (0-0.9)	0 (0-6.2)	0 (0-0.7)	0 (0-6.3)
Vitamin C	0 (0-0.4)	0.1 (0-3.3)	0 (0-0.9)	0.2 (0.1-6.4)	0 (0-0.7)	0 (0-6.3)
Calcium	0.1 (0-0.6)	1.4 (0.2-5.4)	0 (0-1)	0.2 (0.1-6.5)	0.2 (0-1)	2.6 (0.4-10.3)
Bioavailable iron	1.1 (0.6-1.9)	4.4 (1.9-9.5)	0.1 (0-1.1)	1.4 (0.1-8.4)		
menopausal females			NA	NA	0.4 (0-2.2)	3.9 (0.2-22.8)
menstruating females			NA	NA	3.1 (1.7-5.5)	8.6 (2.9-21)
Iodine	4.9 (3.8-6.3)	14.6 (9.5-21.5)	2.2 (1.2-4)	12.4 (6.2-22.6)	7.8 (6-10.1)	16.9 (9.5-27.8)
Selenium	0 (0-0.4)	0 (0-3.2)	0 (0-0.9)	0 (0-6.1)	0 (0-0.7)	0 (0-6.2)
Bioavailable zinc	0 (0-0.4)	0.4 (0-3.9)	0 (0-0.9)	0 (0-6.1)	0 (0-0.7)	0.9 (0-7.7)

NA: Not Applicable

Prevalences of risk of overt deficiency among PB- and PB+ eaters for both sexes, males and females. Results are presented as estimated prevalence with a 95% confidence interval. Stars represent statistically significant differences (non-overlapping confidence intervals).

Supplementary Table S9 – Expected number of averted DALYs by each dietary factor weighted in the comparative risk assessment using the EpiDiet model, in the context of a shift of the population’s diet from the observed diet to the diet of the PB+ eaters

Table S9-A – All individuals

Factor ¹	Ischaemic heart diseases	Diabetes	Cerebrovascular diseases	Bronchus and lung cancers	Colorectum cancer	Pulmonary embolism ²	Rheumatic heart disease	Aortic aneurysm	Heart failure	Hypertensive disease	All diseases	Factor contrib. (%) ³	Factor rank
Processed meats	31770	23577	-	-	-	-	-	-	-	-	55346	32.1%	1
Blood cholesterol	19744	-	2799	-	-	-	-	-	-	-	22543	13.1%	2
Fiber	11953	-	4062	-	5001	-	-	-	-	-	21016	12.2%	3
Fruits (excluding juices)	3451	-	7163	9369	-	-	-	-	-	-	19983	11.6%	4
SFA	16364	-	1509	-	-	-	-	-	-	-	17873	10.4%	5
Nuts & Seeds	6524	8741	-	-	-	-	-	-	-	-	15265	8.9%	6
Red meats	-	9067	-	-	-	-	-	-	-	-	9067	5.3%	7
Dietary cholesterol	7664	-	772	-	-	-	-	-	-	-	8436	4.9%	8
Vegetables (excluding juices)	1945	-	5714	-	-	-	-	-	-	-	7659	4.4%	9
Whole grain	175	570	1176	-	-	-	-	-	-	-	1922	1.1%	10
Total dietary fat	-399	-	626	-	-	-	-	-	-	-	227	0.1%	11
Omega-3 fatty acids	-120	-	-	-	-	-	-	-	-	-	-120	-0.1%	12
Sugar sweetened beverages (SSB)	-756	533	-	-	-	-	-	-	-	-	-223	-0.1%	13
PUFA	-1120	-	-54	-	-	-	-	-	-	-	-1174	-0.7%	14
MUFA	-1538	-	-6	-	-	-	-	-	-	-	-1544	-0.9%	15
Blood pressure	-337	-	-1144	-	-	-	-30	-40	-103	-263	-1916	-1.1%	16.5
Sodium	-337	-	-1144	-	-	-	-30	-40	-103	-263	-1916	-1.1%	16.5
Total ⁴	63498	37075	18231	9369	5001	.	-30	-40	-103	-263	132738	NA	NA

Factor ¹	Ischaemic heart diseases	Diabetes	Cerebrovascular diseases	Bronchus and lung cancers	Colorectum cancer	Pulmonary embolism ²	Rheumatic heart disease	Aortic aneurysm	Heart failure	Hypertensive disease	All diseases	Factor contrib. (%) ³	Factor rank
Disease rank	1	2	3	4	5	6	7	8	9	10	NA	NA	NA

contrib.: contribution

1: Factors are ordered according to their rank in the whole population (male + female).

2: Data were missing to estimate DALYs averted or lost due to pulmonary embolism.

3: Factor contribution calculated as the percentage of the sum of averted DALYs. As explained in table note **Erreur ! Source du renvoi introuvable.**, the sum of DALYs do not correspond to total averted DALYs.

4: It should be noted that since the effects of the different factors are not additive, total averted DALYs do not correspond to the sum of averted DALYs.

NA: Not Applicable

DALYs averted comparing the PB+ diet with the current observed diet in the French adult (18-65 y.o.) population. Observed data are from the Individual and National Study of Food Consumption Survey (INCA) 3. DALYs averted = DALYs estimated for the PB+ diet – DALYs observed in the observed diet

Table S9-B – Males

Factor ¹	Ischemic heart diseases	Diabetes	Cerebro-vascular diseases	Bronchus & lung cancer	Colorectum cancer	Pulmonary embolism ²	Rheumatic heart diseases	Aortic aneurysm	Heart failure	Hypertensive diseases	All diseases	Factor contrib. (%) ³	Factor rank
Processed meats	26962	15968	-	-	-	-	-	-	-	-	42930	38.5%	1
Blood cholesterol	7932	-	747	-	-	-	-	-	-	-	8679	7.8%	5
Fiber	10521	-	2863	-	3583	-	-	-	-	-	16966	15.2%	3
Fruits (excluding juices)	3308	-	6156	8655	-	-	-	-	-	-	18119	16.3%	2
SFA	10229	-	489	-	-	-	-	-	-	-	10718	9.6%	4
Nuts & Seeds	3085	2635	-	-	-	-	-	-	-	-	5720	5.1%	7
Red meats	-	6308	-	-	-	-	-	-	-	-	6308	5.7%	6
Dietary cholesterol	5042	-	356	-	-	-	-	-	-	-	5399	4.8%	8
Vegetables (excluding juices)	1589	-	3413	-	-	-	-	-	-	-	5001	4.5%	9
Whole grain	26	7	256	-	-	-	-	-	-	-	289	0.3%	12
Total dietary fat	-5044	-	-30	-	-	-	-	-	-	-	-5074	-4.6%	17
Omega-3 fatty acids	-105	-	-	-	-	-	-	-	-	-	-105	-0.1%	13
Sugar sweetened beverages (SSB)	-1708	-845	-	-	-	-	-	-	-	-	-2553	-2.3%	16
PUFA	-556	-	-19	-	-	-	-	-	-	-	-574	-0.5%	14
MUFA	-1916	-	-56	-	-	-	-	-	-	-	-1972	-1.8%	15
Blood pressure	334	-	219	-	-	-	2	21	38	153	767	0.7%	10
Sodium	334	-	219	-	-	-	2	21	38	153	767	0.7%	10
Total ⁴	45619	21207	12745	8655	3583	-	2	21	38	153	92023	NA	NA
Disease rank	1	2	3	4	5	10	9	8	7	6	NA	NA	NA

contrib.: contribution

1: Factors are ordered according to their rank in the whole population (male + female).

2: Data were missing to estimate DALYs averted or lost due to pulmonary embolism.

3: Factor contribution calculated as the percentage of the sum of averted DALYs. As explained in table note Erreur ! Source du renvoi introuvable., the sum of DALYs do not correspond to total averted DALYs.

4: It should be noted that since the effects of the different factors are not additive, total averted DALYs do not correspond to the sum of averted DALYs.

NA: Not Applicable

Factor ¹	Ischemic heart diseases	Diabetes	Cerebro-vascular diseases	Bronchus & lung cancer	Colorectum cancer	Pulmonary embolism ²	Rheumatic heart diseases	Aortic aneurysm	Heart failure	Hypertensive diseases	All diseases	Factor contrib. (%) ³	Factor rank
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DALYs averted comparing the PB+ diet with the current observed diet in the French adult (18-65 y.o.) population. Observed data are from the Individual and National Study of Food Consumption Survey (INCA) 3. DALYs averted = DALYs estimated for the PB+ diet – DALYs observed in the observed diet

Table S9-C – Females

Factor ¹	Ischemic heart diseases	Diabetes	Cerebrovascular diseases	Bronchus & lung cancer	Colorectum cancer	Pulmonary embolism ²	Rheumatic heart diseases	Aortic aneurysm	Heart failure	Hypertensive diseases	All diseases	Factor contribution (%) ³	Factor rank
Processed meats	4808	7608	-	-	-	-	-	-	-	-	12417	20.3%	2
Blood cholesterol	11812	-	2051	-	-	-	-	-	-	-	13863	22.7%	1
Fiber	1432	-	1200	-	1419	-	-	-	-	-	4051	6.6%	6
Fruits (excluding juices)	144	-	1007	714	-	-	-	-	-	-	1864	3.1%	11
SFA	6135	-	1020	-	-	-	-	-	-	-	7155	11.7%	4
Nuts & Seeds	3439	6106	-	-	-	-	-	-	-	-	9545	15.6%	3
Red meats	-	2758	-	-	-	-	-	-	-	-	2758	4.5%	8
Dietary cholesterol	2622	-	415	-	-	-	-	-	-	-	3037	5.0%	7
Vegetables (excluding juices)	356	-	2302	-	-	-	-	-	-	-	2658	4.4%	9
Whole grain	150	563	920	-	-	-	-	-	-	-	1633	2.7%	12
Total dietary fat	4645	-	656	-	-	-	-	-	-	-	5301	8.7%	5
Omega-3 fatty acids	-15	-	-	-	-	-	-	-	-	-	-15	0.0%	14
Sugar sweetened beverages (SSB)	952	1378	-	-	-	-	-	-	-	-	2330	3.8%	10
PUFA	-564	-	-35	-	-	-	-	-	-	-	-599	-1.0%	15
MUFA	378	-	50	-	-	-	-	-	-	-	428	0.7%	13
Blood pressure	-671	-	-1363	-	-	-	-32	-61	-141	-416	-2683	-4.4%	16.5
Sodium	-671	-	-1363	-	-	-	-32	-61	-141	-416	-2683	-4.4%	16.5
Total ⁴	17879	15868	5486	714	1419	-	-32	-61	-141	-416	40715	NA	NA
Disease rank	1	2	3	5	4	6	7	8	9	10	NA	NA	NA

1: Factors are ordered according to their rank in the whole population (male + female).

2: Data were missing to estimate DALYs averted or lost due to pulmonary embolism.

3: Factor contribution calculated as the percentage of the sum of averted DALYs. As explained in table note Erreur ! Source du renvoi introuvable., the sum of DALYs do not correspond to total averted DALYs.

4: It should be noted that since the effects of the different factors are not additive, total averted DALYs do not correspond to the sum of averted DALYs.

NA: Not Applicable

DALYs averted comparing the PB+ diet with the current observed diet in the French adult (18-65 y.o.) population. Observed data are from the Individual and National Study of Food Consumption Survey (INCA) 3. DALYs averted = DALYs estimated for the PB+ diet – DALYs observed in the observed diet

Supplementary Table S10 – Expected number of deaths avoided by each dietary factor weighted in the comparative risk assessment using the EpiDiet model, in the context of a shift of the population’s diet from the observed diet to the diet of the PB+ eaters

Table S10-A – All individuals

Factor ¹	Ischemic heart diseases	Diabetes	Cerebro-vascular diseases	Bronchus & lung cancer	Colorectum cancer	Rheumatic heart diseases	Aortic aneurysm	Pulmonary embolism	Heart failure	Hypertensive diseases	All diseases	Factor contrib. ²	Factor rank
Processed meats	920	261	-	-	-	-	-	-	-	-	1181	29.3%	1
Fiber	369	-	100	-	155	-	-	-	-	-	624	15.5%	2
Blood cholesterol	539	-	45	-	-	-	-	-	-	-	584	14.5%	3
Fruits (excluding juices)	103	-	175	300	-	-	-	-	-	-	579	14.4%	4
SFA	485	-	25	-	-	-	-	-	-	-	510	12.7%	5
Nuts & Seeds	187	80	-	-	-	-	-	-	-	-	267	6.6%	6
Dietary cholesterol	204	-	13	-	-	-	-	-	-	-	217	5.4%	7
Vegetables (excluding juices)	54	-	124	-	-	-	-	-	-	-	178	4.4%	8
Red meats	-	112	-	-	-	-	-	-	-	-	112	2.8%	9
Sugar sweetened beverages (SSB)	-6	12	-	-	-	-	-	-	-	-	6	0.1%	10
Omega-3 fatty acids	-4	-	-	-	-	-	-	-	-	-	-4	-0.1%	11
Whole grain	-5	-10	4	-	-	-	-	-	-	-	-10	-0.2%	12
Total dietary fat	-31	-	9	-	-	-	-	-	-	-	-22	-0.5%	13
PUFA	-37	-	-1	-	-	-	-	-	-	-	-38	-0.9%	14
Blood pressure	-10	-	-25	-	-	-1	-1	-2	-4	-8	-51	-1.3%	15.5
Sodium	-10	-	-25	-	-	-1	-1	-2	-4	-8	-51	-1.3%	15.5
MUFA	-51	-	0	-	-	-	-	-	-	-	-52	-1.3%	17
Total ³	1858	408	394	300	155	-1	-1	-2	-4	-8	3100	NA	NA
Disease rank	1	2	3	4	5	6	7	8	9	10	NA	NA	NA

1: Factors are ordered according to their rank in the whole population (male + female).

Factor ¹	Ischemic heart diseases	Diabetes	Cerebro-vascular diseases	Bronchus & lung cancer	Colorectum cancer	Rheumatic heart diseases	Aortic aneurysm	Pulmonary embolism	Heart failure	Hypertensive diseases	All diseases	Factor contribution ²	Factor rank
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²: Factor contribution calculated as the percentage of the sum of death avoided. As explained in table note 3, the sum of deaths avoided do not correspond to total avoided deaths.

Erreur ! Source du renvoi introuvable.³: It should be noted that since the effects of the different factors are not additive, total avoided deaths do not correspond to the sum of avoided deaths.

NA: Not Applicable

Deaths avoided comparing the PB+ diet with the current observed diet in the French adult (18-65 y.o.) population. Observed data are from the Individual and National Study of Food Consumption Survey (INCA) 3. Avoided Deaths = Deaths estimated if 18-65 y.o. adults shifted to the PB+ diet – Deaths observed in the French adult population

Table S10-B – Males

Factor ¹	Ischemic heart diseases	Diabetes	Cerebro-vascular diseases	Bronchus & lung cancer	Colorectum cancer	Rheumatic heart diseases	Aortic aneurysm	Pulmonary embolism	Heart failure	Hypertensive diseases	All diseases	Factor contribution (%) ²	Factor rank
Processed meats	787	196	-	-	-	-	-	-	-	-	983	35.4%	1
Fiber	327	-	75	-	113	-	-	-	-	-	516	18.6%	3
Blood cholesterol	204	-	13	-	-	-	-	-	-	-	217	7.8%	5
Fruits (excluding juices)	100	-	159	284	-	-	-	-	-	-	543	19.6%	2
SFA	313	-	10	-	-	-	-	-	-	-	323	11.6%	4
Nuts & Seeds	91	27	-	-	-	-	-	-	-	-	118	4.3%	8
Dietary cholesterol	130	-	6	-	-	-	-	-	-	-	136	4.9%	6
Vegetables (excluding juices)	45	-	82	-	-	-	-	-	-	-	127	4.6%	7
Red meats	-	87	-	-	-	-	-	-	-	-	87	3.1%	9
Sugar sweetened beverages (SSB)	-42	-7	-	-	-	-	-	-	-	-	-49	-1.8%	15
Omega-3 fatty acids	-3	-	-	-	-	-	-	-	-	-	-3	-0.1%	12
Whole grain	-8	-12	-9	-	-	-	-	-	-	-	-28	-1.0%	14
Total dietary fat	-166	-	-1	-	-	-	-	-	-	-	-167	-6.0%	17
PUFA	-18	-	0	-	-	-	-	-	-	-	-19	-0.7%	13
Blood pressure	12	-	8	-	-	0	1	0	2	5	27	1.0%	10.5
Sodium	12	-	8	-	-	0	1	0	2	5	27	1.0%	10.5
MUFA	-62	-	-1	-	-	-	-	-	-	-	-63	-2.3%	16
Total ³	1343	264	309	284	113	0	1	0	2	5	2321	NA	NA
Disease rank	1	4	2	3	5	10	8	9	7	6	NA	NA	NA

1: Factors are ordered according to their rank in the whole population (male + female).

Erreur ! Source du renvoi introuvable. 2: Factor contribution calculated as the percentage of the sum of death avoided. As explained in table note 3, the sum of deaths avoided do not correspond to total avoided deaths.

3: It should be noted that since the effects of the different factors are not additive, total avoided deaths do not correspond to the sum of avoided deaths.

NA: Not Applicable

Deaths avoided comparing the PB+ diet with the current observed diet in the French adult (18-65 y.o.) population. Observed data are from the Individual and National Study of Food Consumption Survey (INCA) 3. Avoided Deaths = Deaths estimated if 18-65 y.o. adults shifted to the PB+ diet – Deaths observed in the French adult population

Table S10-C – Females

Factor ¹	Ischemic heart diseases	Diabetes	Cerebro-vascular diseases	Bronchus & lung cancer	Colorectum cancer	Rheumatic heart diseases	Aortic aneurysm	Pulmonary embolism	Heart failure	Hypertensive diseases	All diseases	Factor contrib. (%)	Factor rank
Processed meats	133	65	-	-	-	-	-	-	-	-	199	15.8%	2
Fiber	42	-	25	-	42	-	-	-	-	-	109	8.6%	6
Blood cholesterol	336	-	32	-	-	-	-	-	-	-	367	29.2%	1
Fruits (excluding juices)	3	-	16	17	-	-	-	-	-	-	36	2.9%	10
SFA	172	-	16	-	-	-	-	-	-	-	188	14.9%	3
Nuts & Seeds	96	53	-	-	-	-	-	-	-	-	148	11.8%	4
Dietary cholesterol	74	-	6	-	-	-	-	-	-	-	81	6.4%	7
Vegetables (excluding juices)	9	-	42	-	-	-	-	-	-	-	51	4.1%	9
Red meats	-	25	-	-	-	-	-	-	-	-	25	2.0%	11
Sugar sweetened beverages (SSB)	37	19	-	-	-	-	-	-	-	-	55	4.4%	8
Omega-3 fatty acids	0	-	-	-	-	-	-	-	-	-	0	1.5%	14
Whole grain	3	2	13	-	-	-	-	-	-	-	18	11.5%	12
Total dietary fat	135	-	10	-	-	-	-	-	-	-	145	-1.5%	5
PUFA	-19	-	-1	-	-	-	-	-	-	-	-19	-6.2%	15
Blood pressure	-21	-	-33	-	-	-1	-2	-2	-5	-12	-78	-6.2%	16.5
Sodium	-21	-	-33	-	-	-1	-2	-2	-5	-12	-78	0.9%	16.5
MUFA	11	-	1	-	-	-	-	-	-	-	12	15.8%	13
Total ³	514	144	85	17	42	-1	-2	-2	-5	-12	779	NA	NA
Disease rank	1	2	3	5	4	6	7	8	9	10	NA	NA	NA

1: Factors are ordered according to their rank in the whole population (male + female).

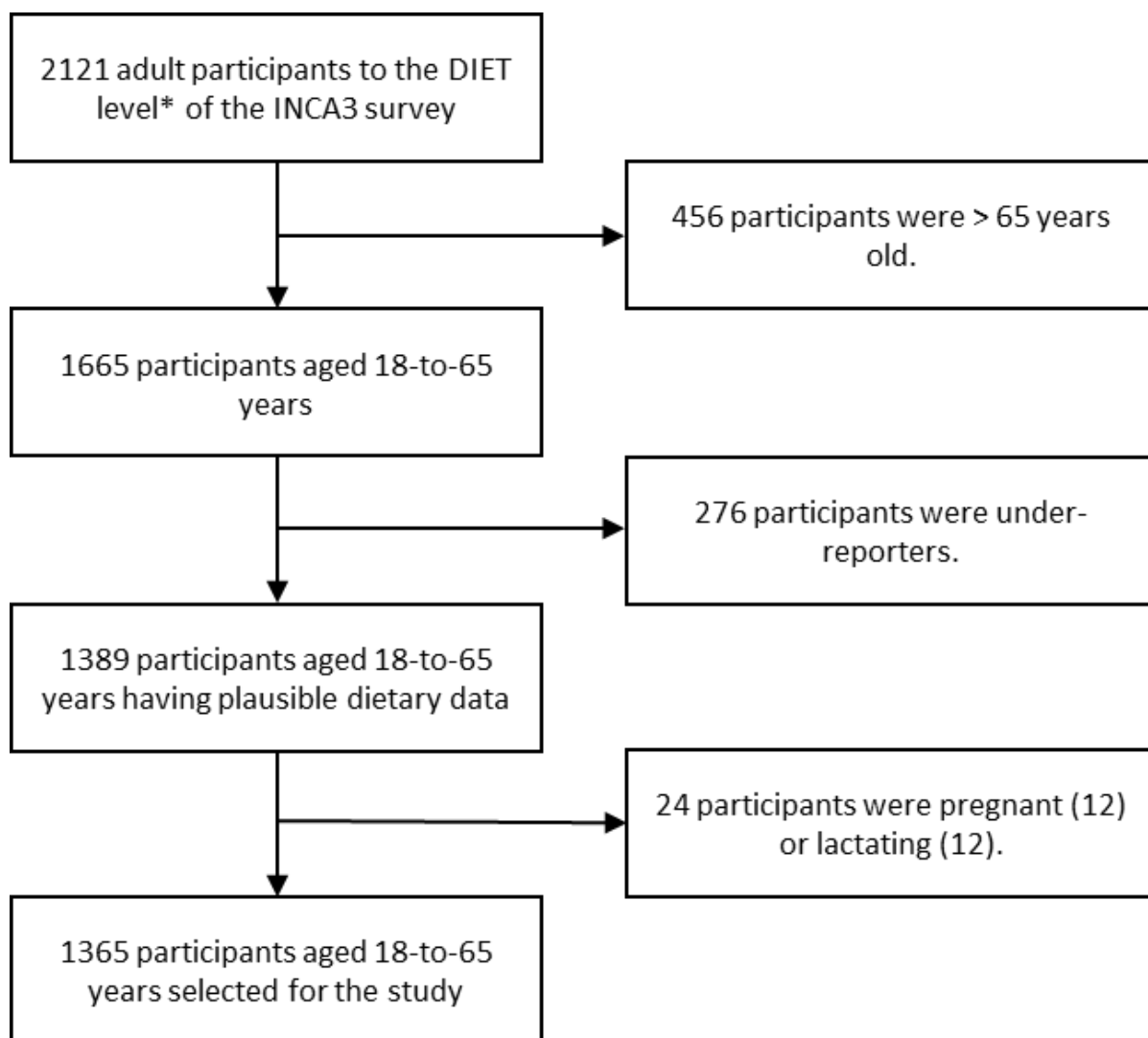
2: Factor contribution calculated as the percentage of the sum of death avoided. As explained in table note 3, the sum of deaths avoided do not correspond to total avoided deaths.

3: It should be noted that since the effects of the different factors are not additive, total avoided deaths do not correspond to the sum of avoided deaths.

NA: Not Applicable

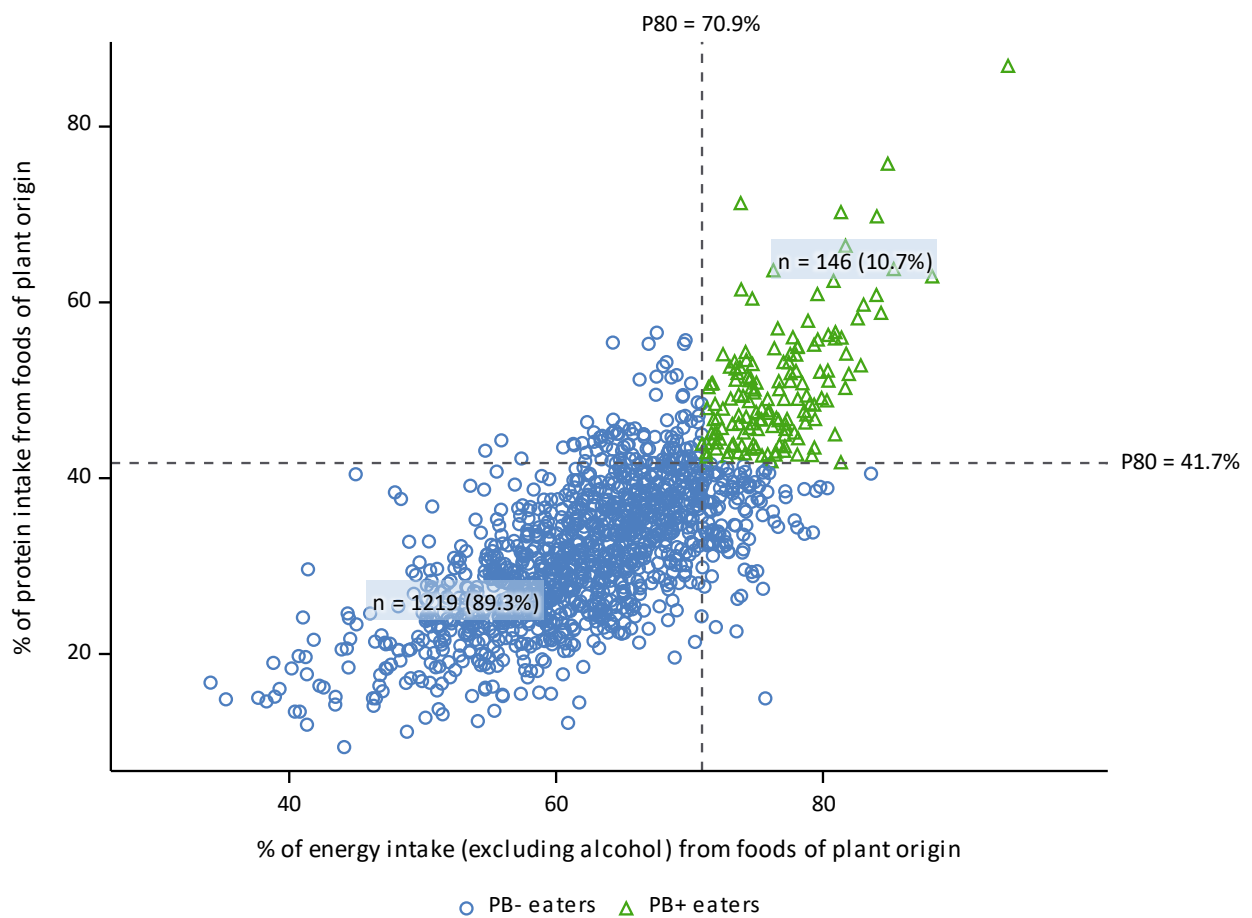
Deaths avoided comparing the PB+ diet with the current observed diet in the French adult (18-65 y.o.) population. Observed data are from the Individual and National Study of Food Consumption Survey (INCA) 3. Avoided Deaths = Deaths estimated if 18-65 y.o. adults shifted to the PB+ diet – Deaths observed in the French adult population

Supplementary Figure S1 – Flow-chart showing the study population sampling



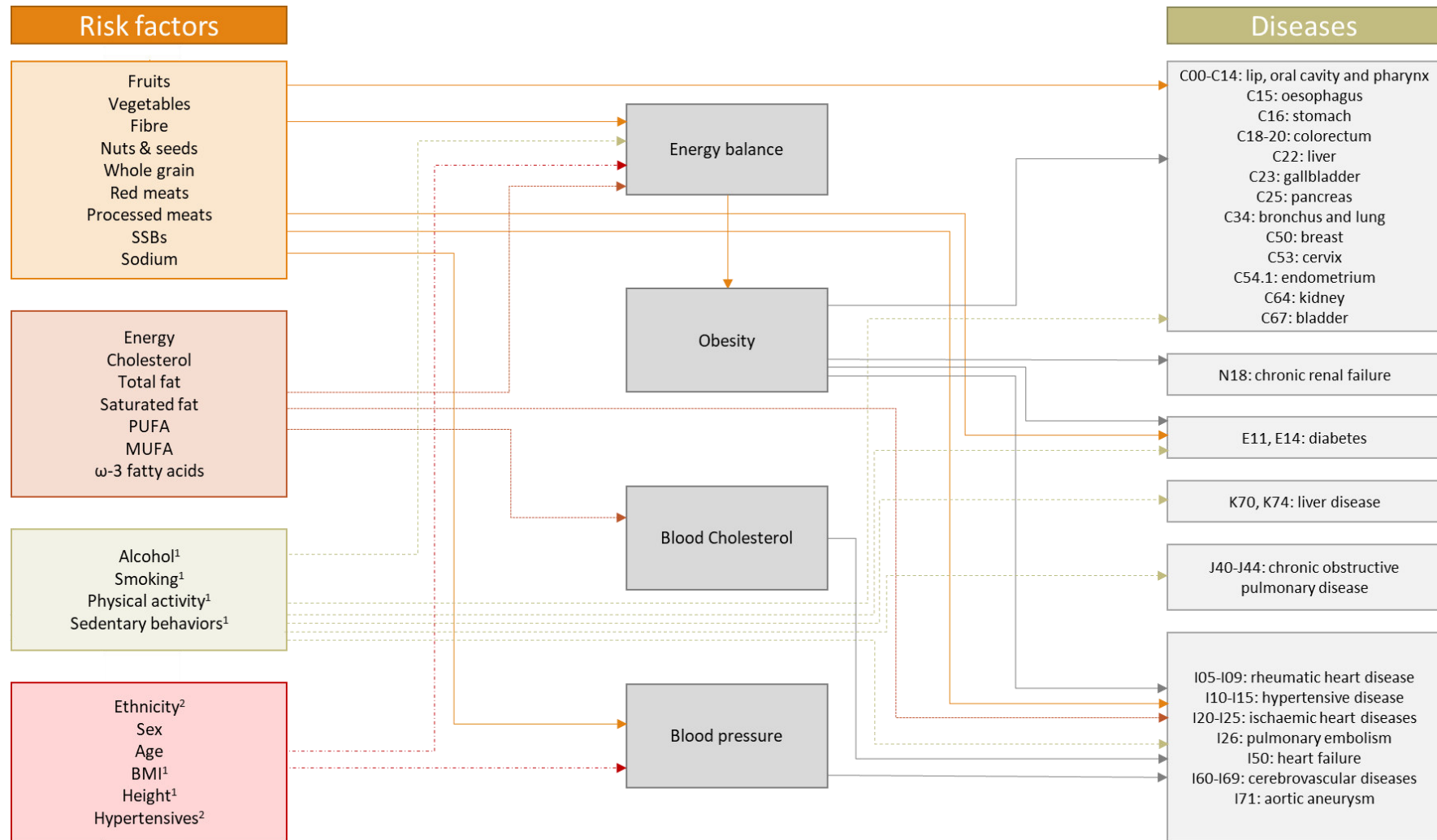
Supplementary Figure S1: Flow chart showing the sampling of the studied population from the French adult participants to the Third Individual and National Study on Food Consumption Survey (INCA3). * The Diet level of the INCA3 survey corresponds to the assessment of dietary intakes using 3 non-consecutive 24h-recalls.

Supplementary Figure S2 – Cut-offs in the study population



Supplementary Figure S2: Each point represents an individual included in the study (i.e. one of the 1365 INCA3 participants aged 18 to 65 years old, excluding pregnant and lactating females and under-reporters). The dotted lines represent the cut-offs used in the study to select PB+ eaters, i.e. the 80th percentile of the share (%) of energy intake (excluding alcohol) from foods of plant origin and the 80th percentile of the share of protein intake from foods of plant origin.

Supplementary Figure S3 – EpiDiet conceptual framework

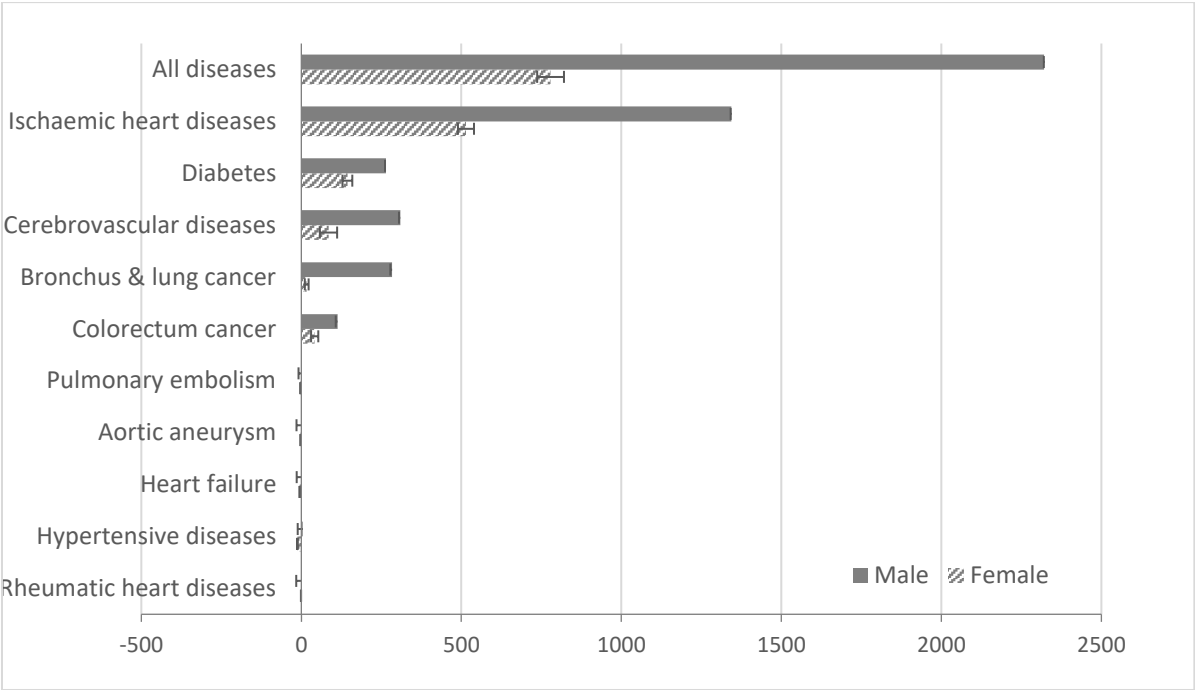


Supplementary Figure S3: Conceptual framework showing the relationships between the risk factors and the diseases implemented in the EpiDiet model. The left column lists the risk factors (foods, macro and micro-nutrients, behaviors and anthropometric measurements), and the right column the diseases considered in the model. In the middle are listed the mechanistic or statistical models implemented in EpiDiet to formulate hypotheses on the mediator factors.

1. Although included in the EpiDiet model, these factors were not considered in our study since we intended to specifically assess the effects of the dietary pattern of PB+ eaters.

2. Although encompassed in the EpiDiet model, these factors could not be considered due to missing/unavailable data.

Supplementary Figure S4 – Estimated avoided deaths



Supplementary Figure S4: Estimated deaths avoided by a shift of the population’s diet from the current diet of French adults to the diet of the PB+ eaters, by sex. Errors bars represent the 95% uncertainty intervals.

Supplementary Method 1 – Iron requirements

As proposed by de Gavelle *et al.*⁷, bioavailable iron intakes have been compared to physiological iron requirements.

For males and non-menstruating females, we used the EAR value derived by EFSA⁸: based on a study conducted by Hunt *et al.*²³, the 50th and the 97.5th percentiles of iron losses were, respectively, estimated to be 0.95 and 1.72 mg/day, thus a coefficient of variation of 40% ($=\frac{1.72-0.95}{2}$).

On the other hand, iron losses are not normally distributed in menstruating females. We modelled the distribution of the iron losses by adding the basal iron losses (normally distributed) to the menstrual losses (exponentially distributed; $\lambda = \ln(2)/0.28$). The basal losses were modelled using the average basal losses of 14 $\mu\text{g}/\text{kg}$ b.w./day derived from the study conducted by Green *et al.*²⁴, the median and variability for basal losses being calculated by using the median and variability for body weight in INCA3 premenopausal women. The menstrual losses were modelled using an exponential distribution, whose λ parameter was derived from the data of the study conducted by Harvey *et al.*²⁵. The total iron losses in premenopausal were generated using a Monte-Carlo simulation on 1,000,000 individuals. Total iron losses followed a lognormal distribution ($p < 0.01$). Thus, it was considered that the logarithm of physiological requirements followed a normal distribution. The parameters of this normal distribution were determined by simulating 1,000 replications of populations of size 10,000 and calculating the mean value of each parameter over the 1,000 replicates: $\mu = 0.24$ and $\sigma = 0.34$ (i.e. $\ln(\text{total iron losses}) \sim N(0.24; 0.34^2)$).

As for iodine, when used to estimate the prevalence of deficiency risk, the above-mentioned nutrient reference values tend to overestimate the prevalence. Thus, as proposed by Salomé *et al.*¹⁸, based on the prevalence of iron-deficiency anaemia in the French population (0.2% in males and 3.9% in females)²⁶, we adjusted these values by dividing them by a factor of 2.07 for males and non-menstruating females (i.e. updated reference value = $\frac{0.95}{2.07}$) and 2.37 for menstruating females (i.e. $\ln(\text{total iron losses}) \sim N(\ln(\frac{e^{0.24}}{2.37}); 0.34^2)$).

Supplementary Method 2 – The EpiDiet model and its application to the present study

General principles

EpiDiet (“Evaluate the Potential Impact of a Diet”) is a simulation-based nutritional and epidemiologic model. Like many other simulation-based risk assessment models^{27,28,29,30}, EpiDiet combines modelling, stochastic and optimization techniques to formulate and analyze connections between diet, nutrition and the risks of non-communicable diseases. Its objective is to quantify the risks and benefits that would result from changes to the diet in an individual or a population.

The conceptual basis and methodological foundation of the EpiDiet model are laid out in the Comparative Risk Assessment framework, which has been proven effective and is used extensively by various groups and organizations such as The EAT-Lancet Commission on Food, Planet and Health³¹, the World Health Organization³², and the Global Burden of Diseases (GBD)³³ to estimate mortality and disability from diseases and other risk factors, including notably dietary and nutrient intakes, climate change, environmental pollution and contaminant exposure.

EpiDiet is a structural risk assessment model used for general purposes into which mechanistic or statistical sub-models can be plugged, and accounts for a wide range of risk factors including nutritional (food, energy and nutrients intakes, and alcohol consumption), lifestyle (sedentary behaviours and physical activity and smoking), and anthropometric (weight and height, age and sex) factors. The model can be used to:

- Compare the prevalence of diseases attributable to the current diet of an observed individual or population versus the prevalence from a hypothetical diet or a series of changes to the diet.
- Identify the optimal diet-related conditions that would contribute to improving health (reducing the incidence of some diseases).
- Access the joint effects of changes to multiple risk factors and draw inferences regarding the effects of combinations of risk factors and differences between risk factors and health outcomes.
- Propagate the sources of uncertainty and estimate their influence on health outcomes.
- Rank risk factors according to their contribution to reducing risks or gaining benefits.

In the EpiDiet model, we estimate the impact of dietary changes on the risks of morbidity and mortality from a set of chronic non-communicable diseases, using the standard computable Potential Impact Fraction (PIF) formula for a dietary factor:

$$PIF = \frac{\int_{x \in X_b} RR(x)P(x)dx - \int_{x \in X_c} RR(x)P'(x)dx}{\int_{x \in X_b} RR(x)P(x)dx}$$

Where $RR(x)$ is the relative risk of the disease at the dietary intake-level x , $P(x)$ denotes the number of individuals in the population whose dietary intake is at level x in the baseline scenario, $P'(x)$ denotes the number of individuals in the population whose dietary intake is at level x in the counterfactual scenario, X_b and X_c are, respectively, the sets of all possible values for x in the baseline and counterfactual scenarios.

It should be noted that the population is stratified by age-band and sex in order to better take account of disparities in diet, diseases and relative risks between individuals.

To access the joint effects of changes to multiple dietary factors, we use the following joint PIF formula derived from the concept of the Population Attributable Fraction (PAF), as classically found in GBD (Global Burden of Disease) studies³⁰:

$$PIF_{joint} = 1 - \prod_{f=1}^M (1 - PIF_f)$$

Where f denotes each individual dietary factor and M is the total number of factors considered in the model. We assume that dietary factors are independent and uncorrelated, and the corresponding relative risks are mutually adjusted for potential confounding.

We describe the sources of uncertainty and quantify their propagation within the model, revealing the range of their potential impact on health outcomes. To access this metric, we use a Monte Carlo-based simulation, which involves iteratively substituting a range of values, in the form of a probability distribution, for any factor with inherent uncertainty, and aggregating the variation in the output that results from the uncertain factors in the inputs. In practical terms, we draw 100,000 samples at random for each relative risk according to its distribution and calculate the 95-% uncertainty intervals (UI) of the outcome using the 2.5th and 97.5th percentiles of the simulation results.

Finally, sensitivity analyses are performed to rank the risk factors according to their contribution to the change in the global risk³⁴. We report several metrics for each risk factor, including the part of risk reduction that is attributable to the factor.

Scenario Design

As mentioned in the [General principles](#), the EpiDiet model rests on the comparison of a baseline and a counterfactual scenario.

In this study, the baseline scenario was derived from the food consumption observed in 18-to-65-year-old adults during the most recent French survey: the third Individual and National Study on Food Consumption Survey (INCA3)⁵. We used recipes to break down complex foods into ingredients to estimate as precisely as possible the intake of each food (or beverage) group corresponding to a risk factor of interest. We used the 2016 version of the CIQUAL Food composition database³⁵ to determine the intake of energy and nutrients included in the model as risk factors. As described in the Materials and Methods of the manuscript, under-reporters were identified using the basal metabolic rate estimated by Henry's equation³⁶ and the cut-off values proposed by Black³⁷, and were excluded from the analyses. The dietary pattern of the baseline scenario corresponded to the daily average intake of each food and beverage group per capita in this adult sub-population.

The counterfactual scenario was derived from the diet of the PB+ eaters, a sub-sample of INCA3 individuals whose shares of energy and protein intakes from plant-based foods were equal to or greater than the 80th percentile of the study population. These individuals were identified as described in the Materials and Methods section of the manuscript.

Data used

In this study, as mentioned in **Erreur ! Source du renvoi introuvable.**, we used dietary data from the most recent Individual and National Study on Food Consumption Survey in France (INCA3), collected in 2014-2015⁵. We generalized the scenarios formed above to the whole French population, considering INCA3 weight variable. It should be noted that this weight variable was derived using a standardized weighting method based on recalibration that accounts for sex, age, educational attainment, geographic location and type of eating in order to correct imbalances between the samples in the survey and the target population³⁸.

Data on population demographics (structure and mortality) and national disease-specific deaths in 2014, thus matching the time of collection of consumption data, were supplied by the National Institute of Statistics and Economic Studies³⁹ and the Epidemiological Centre on Medical Causes of Death⁴⁰, respectively.

We selected diseases and risk factors for which the hazards from mutually controlled risks were available (found either directly in the literature or estimated from data published in high-quality meta-analyses), and implemented methods to take account of the joint effects of changes to multiple risk factors.

In this study, we set up the EpiDiet model using the RR values reported in recent high-quality international meta-analyses^{30,41}. Then, for each scenario, input data included the consumption of fruit (mean and SD, percentage of low consumers of fruits), vegetables (mean and SD, percentage of low consumers of vegetables), whole grains (mean and SD), nuts & seeds (mean and SD), omega-3 (mean and SD), red meats (mean and SD), processed meats (mean and SD), SSB (mean and SD), alcohol (mean and SD, percentage of low consumers), salt (mean and SD), intakes of fiber (mean and SD), total fat (mean and SD), monounsaturated fatty acids (MUFA) (mean and SD), polyunsaturated fatty acids (PUFA) (mean and SD), saturated fatty acids (SFA) (mean and SD), cholesterol (mean and SD), and energy intake (mean).

Food intakes were supposed to be isocaloric and controlled over the total energy intake by relating dietary and nutrient intakes to the average total energy intake within the population.

The exceptions were salt which is little associated with energy intake and total fat, monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) and saturated fatty acids (SFA), the intakes of which were expressed as percentages of total energy intake excluding alcohol.

The list of chronic diseases related to diet were provided by the Epidemiological Centre on Medical Causes of Death. These diseases defined according to the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10)⁴².

Estimate of DALYs attributable to dietary factors

Disability Adjusted Life Years (DALYs) were estimated. The DALY is a normalized disease burden metric. It measures the number of years lost due to living with disease or dying before a predetermined life expectancy, and includes two components: the premature mortality component (expressed in YLLs - Years of Life Lost) and the morbidity component (expressed in YLDs - Years Lived with Disability).

The premature mortality component (YLLs) is defined as the number of potential years of life lost due to premature death. YLLs are computed by multiplying the number of premature deaths at each age by a standard life expectancy at that age. In this study, the number of premature deaths was computed using the EpiDiet model and the standard expectation of life was extracted from the lifetables supplied by the GBD Group and available in the GBD Results Tool (<https://vizhub.healthdata.org/gbd-results/>).

The morbidity component (YLDs) is defined as the equivalent years of healthy life lost because of states of poor health or disability. YLDs are estimated as the incidence of cases of different disease sequelae multiplied by the duration and disability weighting of each sequela. Our estimates of YLDs were calculated by multiplying the total YLLs by a conversion rate specific to age, sex and disease, which was calculated from the estimates provided by the GBD Group 2017 study⁴³ via the GBD Results Tool (<https://vizhub.healthdata.org/gbd-results/>). The use of a conversion rate made it possible to bypass the procedures for estimating disease duration as they are usually complex, requiring dynamic modelling and conservative assumptions^{44,45}.

Furthermore, as mentioned in the **General principles**, uncertainty analysis on measurement error was performed to evaluate the influence that variability of the diet-disease relative risk estimates due to sampling error has on the health impact of dietary changes. First, we estimated the probabilistic distributions of the actual relative risk using data reported in published meta-analyses, and then drew 100,000 stochastic simulations using Monte Carlo simulation. Each simulation was propagated to the health outcomes. The corresponding uncertainty intervals (UI) are based on the 2.5th and 97.5th percentiles of the outputs.

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