



HAL
open science

Potential unexpected effects of meat reduction in diet: Could educational attainment influence meat substitution strategies?

Pierre Levasseur, François Mariotti, Isabelle Denis, Olga Davidenko

► To cite this version:

Pierre Levasseur, François Mariotti, Isabelle Denis, Olga Davidenko. Potential unexpected effects of meat reduction in diet: Could educational attainment influence meat substitution strategies?. *Agricultural and Food Economics*, 2024, 12 (1), pp.4. 10.1186/s40100-024-00298-7. hal-04426863

HAL Id: hal-04426863

<https://hal.science/hal-04426863v1>

Submitted on 30 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.




Distributed under a Creative Commons Attribution 4.0 International License

RESEARCH

Open Access



Potential unexpected effects of meat reduction in diet: Could educational attainment influence meat substitution strategies?

Pierre Levasseur^{1*} , François Mariotti², Isabelle Denis² and Olga Davidenko²

*Correspondence:
pierre.levasseur@inrae.fr

¹ UMR SADAPT, INRAE, AgroParisTech, Université Paris-Saclay, Campus Agro Paris Saclay, 22 Place de l'Agronomie, CS80022, 91120 Palaiseau Cedex, France

² UMR PNCA, AgroParisTech, INRAE, Université Paris-Saclay, Palaiseau Cedex, France

Abstract

Regulation of meat consumption appears to be a relevant public policy to limit diet-related greenhouse gas emissions. However, the real impact of such a policy (e.g., tax) on human health and nutrition remains uncertain, especially for underprivileged individuals. Based on representative data from France, we estimate potential trend differences in the association between meat consumption and nutritional outcomes, such as body mass index (BMI) and unhealthy food intake, according to individual educational attainment. We reveal that among adults with low education levels, reduced meat consumption was significantly associated with a higher BMI, a higher risk of being overweight, and greater intake of ultra-processed foods, sweet drinks, and sugar. By contrast, reduced meat consumption was associated with healthier nutritional status for the most educated individuals. These results are robust to several measurements of socioeconomic status (SES) such as household income, occupation, and financial insecurity perception. In summary, high-SES individuals may be more prone to replace meat with healthy alternatives, whereas low-SES individuals may tend to replace meat with energy-dense foods and beverages, including ultra-processed foods. In terms of the contribution to science and society, this study is the first to show that SES changes the relationship between meat consumption and nutritional outcomes. Our findings call for future research on this topic to provide actionable recommendations to implement a fair and healthy food transition.

Keywords: Meat, Socioeconomic status, Body mass index, Overweight, Diet quality

Introduction

Overconsumption of meat is a widespread issue in high-income countries, including France, where individual consumption of animal products exceeds the international requirements and recommendations for a significant proportion of the population (WHO 2023). In such countries, regulating meat consumption, for example, through implementation of tax and quality norms, appears to be a relevant public policy to

limit the food-related carbon footprint and reduce public health expenditures (Springmann et al. 2018, 2016).¹

Although an increase in meat price, implying a decrease in its consumption on average, is expected to be beneficial for the planet, the impacts on human health and nutrition are more uncertain. In fact, most cohort studies that observed potential health and nutritional benefits associated with low-meat diets (e.g., Le and Sabaté 2014; Satija et al. 2019; Dinu et al. 2017) may suffer from sample selection bias. Indeed, analyzed samples are often sociodemographically unbalanced and give a biased picture of the population; typically, they are characterized by higher education levels, incomes, and rates of women (e.g., Spencer et al. 2003; Mozaffarian et al. 2011; Vergnaud et al. 2010; Rosell et al. 2006). Yet this lack of representativeness in the data may contribute to overstating the protective nutritional impacts of a meatless diet. It is likely that wealthier and more educated individuals have a greater interest in health and nutrition, and thus a greater willingness to adopt healthier behaviors and a more diversified diet than poorer and less educated individuals.² Such a sample selection bias might explain why the protective effects of low-meat diets are not confirmed by experiments based on randomized control trials (RCTs). For instance, a recent meta-analysis cumulating 19 RCTs with a median duration of 12 weeks showed that participants assigned to meat- and/or dairy-reduced diet had lower protein intake than participants receiving control diets, but no significant gap was observed regarding bodyweight outcomes and fat composition (Habumugisha et al. 2023).

A potential sample selection bias in previous studies justifies the need to reexamine the association between meat consumption and nutritional outcomes by focusing on potential heterogeneity according to household socioeconomic status (SES), and especially educational attainment. Indeed, because higher education is significantly associated with healthier eating habits, including increased consumption of fruits, vegetables, and whole grain foods (Darmon and Drewnowski 2008), educational attainment is likely to influence meat substitutes in a context of reduced meat intake. In Western high-income countries, meat remains an important source of protein and indispensable nutrients including vitamin B12, zinc, and iron (Dussiot et al. 2022). People with lower SES rely more heavily on meat for their protein intake, and their diet is less in line with dietary guidelines and nutrient reference intake (ANSES 2017). Therefore, it is important to consider the impact that reducing meat consumption could have on the diet quality of lower socioeconomic segments of the population. Diets lower in meat might be protective for individuals with higher education and detrimental for individuals with lower education levels.

¹ Livestock farming, especially the beef sector, causes greater greenhouse gas emissions than those produced by other agricultural activities, and reducing red meat in the diet is thus one possible way to reduce the environmental impact of the food system (Springmann et al. 2016). Increased consumption of red meat and processed meat is also suspected to increase the prevalence of overweight and obesity, as well as the risk of type 2 diabetes, stroke, colorectal cancer, and all-cause mortality (Boutron-Ruault et al. 2017). Currently, national dietary guidelines are starting to include recommendations for maximum levels of meat intake. In France, for example, the recommended maximum intake of meat (excluding poultry) is 70 g per day (500 g per week) and that of processed meat is 25 g per day (ANSES 2016). In 2016, more than 20% of French adults exceeded these thresholds (Crédoc 2016; Mollier 2019). For more references regarding the environmental impacts of meat production and consumption, please refer to Crippa et al. 2021; Mekonnen and Hoekstra 2010; Scarborough et al. 2023.

² Concerning the cohorts used in most previous studies, the NutriNet-Santé cohort (France) includes only self-enrolled participants, resulting in an overrepresentation of educated and female individuals; the Adventist cohort (US and Canada) is composed exclusively from the members of the Seventh-Day Adventist church, which promotes a healthy lifestyle (Butler et al. 2008). A similar sample bias may be attributed to the study by Satija et al. (2019), which focuses on a very specific population group of medical professionals.

In this study, we explore potential differences in meat substitution strategies according to educational attainment. Because of economic and cultural constraints, lower-educated populations might be more likely than higher-educated populations to replace meat with fat and carbohydrates, because many alternative sources of protein (e.g., fish, dairy products, and plant proteins) are more expensive and (geographically and culturally) less accessible than palatable high-fat and high-sugar foods (Darmon and Drewnowski 2008; Magrini et al. 2017; Maillot et al. 2007; Monnery Patris et al. 2019). These behaviors might further increase the risk of diet-related diseases among low-SES populations already highly affected by overweight status and obesity.³ To avoid an increase in nutritional inequality, there is a need to better understand the potential nutritional impacts of reducing meat consumption for different education groups.

Based on a representative adult sample from France [INCA3 2015], this article firstly proposes to explore potential gaps in nutritional outcomes across education groups when meat consumption is low. Specifically, we determine whether individual education modifies the association between meat consumption and nutritional outcomes, considering body mass index (BMI measured in kg/m²) and its classification (i.e., overweight versus non-overweight), diet indicators (i.e., daily energy intake in Kcal/day and the share of ultra-processed foods (UPF) in daily energy intake), risky food/beverage intakes (i.e., consumption of sweets, sweet drinks, and snacks in g/day), and macronutrient composition of the diet (i.e., sugars, fats, and proteins in g/day). Obviously, given the observational method used, this study does not claim to demonstrate causal effects. Indeed, the risk of endogeneity due to reverse causality (e.g., higher BMI implying greater calorie intake) and unobserved heterogeneity (e.g., experience in composing low-meat diets) can never be excluded when cross-sectional data are used. Nevertheless, our originality lies in using representative health and nutrition data to first demonstrate correlational evidence for an understudied research question and then provide new insights to be tested in future research. The results will be discussed from a critical perspective, considering their policy implications. The findings stress the need for further research to take into account social inequalities from the perspective of promoting reduced-meat diets.

The rest of the article is structured as follows. Sect. "Methods" describes the methods, and Sect. "Results" reports the results. Finally, Sect. "Discussion" and Sect. "Policy implications" respectively discuss the findings and policy implications, and Sect. "Limitation and research perspectives" puts the study limitations into perspective to propose future research.

Methods

Data and sample

The INCA3 (French National Individual Survey on Food Consumption, round 3) is the most recent nationally representative cross-sectional individual survey conducted by the French National Agency for Food, Environment, and Occupational Health & Safety

³ Replacing animal protein with plant-based products favors the nutritional adequacy of the diet when the plant protein is obtained from foods of high nutritional value such as whole grains, nuts, seeds, legumes, and vegetables (Salomé et al. 2020). In contrast, diets rich in affordable "unhealthy" plant foods (e.g., fruit juices, sweetened beverages, refined grains, fried potatoes, sweets, and desserts) are associated with increased risk of weight gain, type 2 diabetes, and coronary disease over time (Satija et al. 2019, 2017, 2016).

(ANSES) in 2014–2015. It includes data on 3,157 adults aged 18 to 79 years and 2,698 children aged 0 to 17 years (Dubuisson et al. 2019). This survey is particularly appropriate for our research question insofar as INCA3 has the advantage of providing detailed individual information on reported food and beverage consumption, economic and sociodemographic characteristics, and objective anthropometric measurements (i.e., height and weight) obtained using scales and stadiometers at home. As recommended by the survey administration, our statistical and econometric analyses were balanced using the weights provided in the INCA3 database so that the results are representative of the French population.

We restricted our sample to non-pregnant and non-lactating adult individuals and excluded adults over the age of 65 years. Hence, all of our analyses are representative of the French adult population aged from 18 to 64 years. This restricted sample includes approximately 1,400 adults.

Econometric model and variables

To test our hypotheses, we performed linear regressions of several nutritional outcomes on SES indicators, meat consumption measures, their mutual interactions, and a comprehensive set of covariates. Specifically, for each considered dependent variable Y_i , we regressed the following ordinary least square estimation model:

$$Y_i = \beta_0 + \beta_1 SES_i^j + \beta_2 Meat_i + \beta_3 SES_i^j * Meat_i + \beta_4 X_i + \varepsilon_i$$

Y_i refers to four types of outcomes that characterize the nutritional profile of an individual i . We considered the following: (i) the individual nutritional status, measured by BMI (in kg/m^2) and overweight/obesity status (i.e., a binary variable that takes the value 1 if BMI is higher than $25 \text{ kg}/\text{m}^2$, 0 otherwise); (ii) the individual diet, measured by the daily energy intake excluding alcohol intake (in Kcal/day) and the share of UPF in daily energy intake based on the application of the NOVA classification to the INCA3 food repertoire (as previously described in Salomé et al. 2021); (iii) the individual consumption of some food and beverage that are commonly considered as unhealthy such as sweet drinks (including soft drinks and fruit juices), sweets (including bakery products, cakes & biscuits, desserts, ice creams, chocolates & candies, and other sugars), and snacks (including pizza, burgers, sandwich, quiche, and other salted snacks) in g/day; (iv) the individual diet composition in macronutrients, measured by sugar (a part of carbohydrates), fat, and protein intakes in g/day.

In the set of independent variables, SES_i^j refers to the SES of an individual i and $Meat_i$ refers to the amount of meat an individual i eats in 1 month. In order to explore the association between nutritional outcomes and meat consumption according to SES, we introduced an interaction term between the two factors of interest ($SES_i^j * Meat_i$). Using this interaction term, we could determine whether the associations between meat consumption and nutritional outcomes are significantly different from one group j of SES to another group j .

There are several ways to measure an individual's SES since this concept is multifactorial and includes economic, cultural and social dimensions (Bourdieu 2002), respectively, approximated by household income, educational attainment, and occupation in

empirical studies. In this study, we tested our model relying on these three dimensions, but only report education-based results in the main document.⁴ Educational attainment was measured using a categorical indicator derived from a discrete score measuring the highest diploma obtained by an individual (varying from 1 for individuals never schooled to 12 for postgraduate education). Based on this score, three levels j of diploma completion were defined ($j = 1$: no diploma; $j = 2$: a technical or professional diploma, including a middle school diploma; $j = 3$: at least a high school diploma). Additional estimates based on alternative measurements of SES are reported in the Appendix, by considering three groups of household income based on sample tercile ($j = 1$: less than 1,750 €/month; $j = 2$: middle incomes; $j = 3$: more than 3,850 €/month), four occupation groups based on the international standard classification ($j = 1$: workers engaged in occupations requiring manual labor or heavy machinery; $j = 2$: workers engaged in skilled or semi-skilled jobs; $j = 3$: professionals and workers engaged in executive, administrative or clerical duties; $j = 4$: inactive), and a binary variable of financial insecurity perception (in which j takes the value 1 if the respondent declares financial difficulties at the end of the month, 0 otherwise).

We measure meat consumption in g/month by multiplying the number of days per month an individual consumes meat (estimated from a retrospective period of 12 months before the survey) with the number of grams consumed per day (estimated from a 3-day food diary with a 24h recall).⁵ We included in this measurement of meat consumption beef, pork, poultry, lamb, offal, sausages, terrines, and other mixtures, but excluded dishes that may partially include meat like stew and snacks insofar as the amount of meat in these dishes is highly uncertain. As shown in Fig. 6 in the Appendix, this exclusion is unlikely to affect our results given the absence of significant gaps in stew and snack intakes across education groups. Based on a boxplot analysis, we considered as extreme values individuals that declare to consume more than 6 kg/month of meat and exclude them from the analysis. Hence, meat consumption varied from 0 to 6 kg/month. Distributions of meat consumption by education group are available in Fig. 7 in the Appendix.

In the set of control variables, X_i , we included the main determinants of nutritional outcomes, excluding energy intake which is considered a dependent variable in the model. Concretely, we controlled for demographic factors such as age group (i.e., 18–44, or 45–64), sex, and household composition (number of children and adults), as well as for environmental factors such as the degree of urbanicity of the living area (i.e., rural, small city, medium size city, large city, and the Paris agglomeration) and the region of residence. We also controlled for individual habits including lunch location (at home or outside), declaring oneself as vegetarian or not, daily smoking (a binary-response variable), an alcohol consumption score varying from 0 to 90 (which is the sum of days/month when an individual consumes wine, days/month when an individual consumes beer,

⁵ In alternative (unreported) regressions, we tested other measurements of meat consumption: (i) the number of days per month an individual consumes meat, and (ii) the number of grams of meat consumed per day. The results were systematically similar (available upon request).

⁴ Note that the educational dimension is consensually preferred in cross-sectional studies to measure SES because this factor does not widely vary across time among adult populations (Daran and Levasseur 2022). By contrast, household income, and to a lesser extent, individual occupation, might be preferred in longitudinal studies relying on time-fixed effect models, because both factors are time-varying.

and days/month when an individual consumes cider), and the levels (i.e., low, medium, or high) of physical activity (e.g., sport) and sedentary activity (e.g., time spent sitting in front of screens) directly calculated by the INCA administration using the average daily time allocated to both types of activity. Furthermore, we systematically controlled for possible under- and over-reporting using the Goldberg/Black method provided by the INCA3 survey administration (Dubuisson et al. 2019), as well as for the season the respondent was surveyed.⁶ Finally, in regressions in which daily energy intake was considered a dependent variable, we controlled for the basal metabolic rate of an individual to deal with the potential problem of reverse causality.

Model assumptions regarding unobserved heterogeneity issues

Given the cross-sectional structure of the data, our empirical strategy relies on a static model in which we assume that diet balancing and substitution strategies are definitely decided by individuals and will not change over time. We are conscious of the strength of this assumption and discuss future research perspective in Sect. "Limitation and research perspectives" to relax this assumption. One can indeed assume that individuals who have been on a low-meat diet for a while will be more experienced with healthier meat alternatives compared to individuals who have recently reduced their meat intake. The former could indeed have improved their feeding behaviors because of noticing changes in their body or health, or under the advice of their doctor. Thus, a higher proportion of long-term low-meat eaters among upper education groups might bias the estimates, with their longer experience resulting in healthier meat substitutes and a lower BMI (i.e., overestimation of the protective effects induced by a low-meat diet). By contrast, if individuals with lower education levels tend to have a shorter experience with a low-meat diet, they may be more subject to risky meat substitutes and weight gain (i.e., underestimation of the protective effects induced by a low-meat diet). Although the duration of having or not having a low-meat diet cannot be directly measured from the data, some evidence supports the validity of our estimates. As shown in Table 1, it is reassuring to observe no significant gap in the rates of declared vegetarian diets across education groups. In fact, the total amount of meat intake was even the lowest among individuals without a formal diploma (cf. Fig. 6 in the Appendix). Based on these facts, we assume for this exploratory study that the level of experience (in terms of duration) in composing a low-meat diet is relatively similar across SES' groups, thus our OLS estimates are not biased by such a problem of unobserved heterogeneity.

In addition to potential unobserved time-varying heterogeneity as discussed above (experience), our model might be biased because of the omission of time-invariant heterogeneity. For instance, higher educated individuals may disproportionately live in richer areas well doted in health services and alternative food stores (selling plant proteins for example), both factors being theoretically negatively correlated with meat intake and BMI (Méjean and Recchia 2022). Given the lack of data, we were unable to accurately disentangle the real effect of educational attainment from the effect of local amenity

⁶ For more information concerning the calculation of these variables, please refer to the survey website and related documents, available on: <https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudes-alimentaires-de-letude-inca-3/>

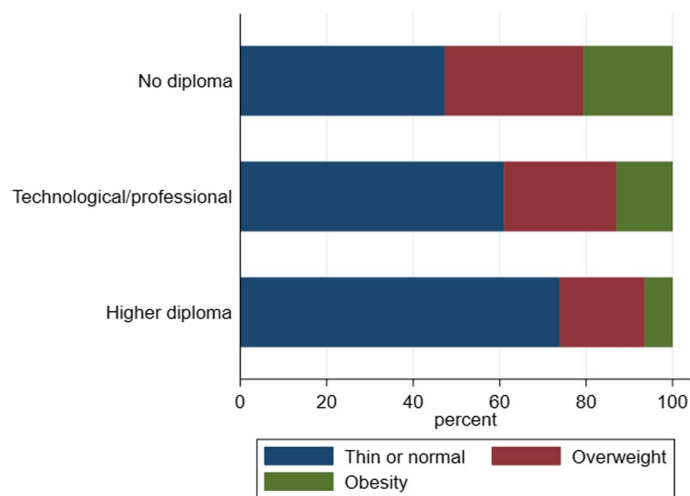


Fig. 1 BMI classification across education groups. *Notes* Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). The BMI-based classification used is thin or normal (BMI < 25 kg/m²); overweight (25 < = BMI < 30 kg/m²); obese (> = 30 kg/m²). Source: INCA-3 (2014–2015)

exposure. However, it can reasonably assumed that, among adult populations, educational attainment (and more largely SES) is associated with residential location, which renders our result relatively robust to such a source of unobserved heterogeneity. In further studies, it will be however interesting to introduce measurements of local amenities into the model to test for potential heterogenous effects.

Results

Descriptive statistics

Table 1 lists weighted sample means for most explanatory variables among the whole sample, as well as among each education group. Educational attainment is divided into three groups based on the highest diploma an individual obtained: basic education (i.e., attended primary school at most, no formal diploma), intermediate education (i.e., technical or professional diploma, including middle school diploma), and advanced education (i.e., high school and university degrees). Compared to others, individuals with basic education (i.e., no formal diploma) tended to be older (i.e., 76% belongs to the 45–64 age group) and were characterized by lower meat and alcohol intakes. In contrast, the most educated individuals tended to have more children and a more "mondain" lifestyle (e.g., living a bit more in large cities, consuming alcohol more frequently, eating lunch less often at home, and being physically more active). Regarding individuals with intermediate education, they disproportionally lived in rural areas and were less physically active than others. Based on Fig. 1, it is interesting to note that overweight and obesity statuses are the most prevalent among individuals with a basic education, and the least prevalent among the most educated individuals. This type of nutritional inequality is consistent with other studies based on France and high-income countries (Darmon 2008).

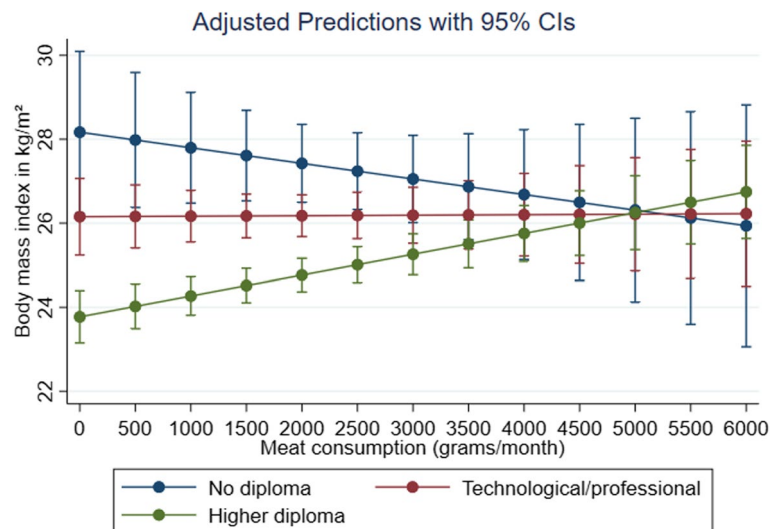


Fig. 2 Fitted BMI across household income and education groups. *Notes* Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black’s index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014–2015)

Multivariate estimates

Table 2 reports regression results when continuous BMI and overweight/obesity status were used as dependent variables. Globally, the models fit relatively well; the explanatory variables captured 24% of BMI variations across individuals (19% of overweight status variations). Moreover, the fitted coefficients of control variables had an expected sign, in accordance with the health economics literature on the determinants of BMI (e.g., Bonnefond and Clément 2014; Levasseur 2015; Clément 2017). Indeed, being older, a low level of physical activity, and family size, were positively associated with BMI and overweight status.

Regarding the fitted coefficient of the interaction term (in bold in Table 2), the sign and significance confirmed our hypothesis. Estimates indicated that among the most educated individuals, 1 extra kg of meat consumption in 1 month was significantly associated with a higher individual BMI, by 0.87 kg/m² on average, and a higher risk of being classified as overweight, by 0.95 percentage point on average, compared with individuals with no diploma ($p < 0.05$). Figure 2 plots the fitted marginal effects (at mean points) of meat consumption on adult BMI for each education group (based on Column 1 of Table 2). This figure clearly illustrates the existence of a diploma-specific association between meat consumption and BMI, which was significantly positive for the most educated individuals ($p < 0.05$), but significantly negative for individuals without diploma ($p < 0.05$). For the intermediate education group, the trend was flat and non-different from 0. Note that these SES-specific trends were robust for different SES measurements, i.e., household income groups, occupation groups, and financial insecurity perception by the respondent (Fig. 8 in the Appendix).

To increase our understanding of potential pathways that may explain why low-meat eaters with low-SES tended to have a higher BMI and a higher risk of being overweight

Table 1 Descriptive statistics across education groups

	All adults (aged 18–64)		Basic education (without diploma)		Intermediate education (professional and technical diploma)		Advanced education (at least a high school degree)	
	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
Body mass index (kg/m ²)	25.65	0.19	28.28	0.78	26.35	0.32	24.39	0.22
Overweight/obesity status (binary)	0.50		0.76		0.54		0.40	
Meat consumptions (g/month)	1862	61.25	1574	162	1880	93	1924	110
Male (binary)	0.48		0.41		0.49		0.50	
Aged 45–64 (binary)	0.45		0.76		0.50		0.33	
Daily smoking (binary)	0.25		0.30		0.29		0.19	
Alcohol cons. index (0-to-90 score)	10.70	0.49	6.53	1.00	9.72	0.93	12.74	0.66
Medium physical activity (binary)	0.47		0.43		0.59		0.37	
High physical activity (binary)	0.16		0.10		0.09		0.23	
Medium sedentari-ness (binary)	0.42		0.50		0.49		0.34	
High sedentariness (binary)	0.46		0.41		0.37		0.55	
Lunch at home (binary)	0.53		0.74		0.59		0.43	
Declared as vegetar-ian (binary)	0.02		0.02		0.03		0.01	
Number of adults per household	2.14	0.04	2.18	0.13	2.22	0.07	2.06	0.07
Number of children per household	0.81	0.05	0.52	0.12	0.73	0.08	0.97	0.08
Rural area (binary)	0.26		0.17		0.36		0.20	
Small city [2000–20000 inhpts] (binary)	0.18		0.26		0.19		0.14	
Middle size city (binary)	0.13		0.15		0.15		0.10	
Large city > = 100,000 inhpts (binary)	0.30		0.32		0.22		0.37	
Paris' urban area (binary)	0.14		0.11		0.08		0.19	
OBSERVATIONS	<i>n</i> = 1,318; <i>N</i> = 29,354,406		<i>n</i> = 101; <i>N</i> = 3,496,348		<i>n</i> = 537; <i>N</i> = 12,165,691		<i>n</i> = 671; <i>N</i> = 13,378,632	

Means and standard errors are weighted using the survey recommendations to guarantee the representativeness of the sample. *N* refers to the population size and *n* refers to the sample size. HH means household. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). For each row variable, mean-comparison tests were processed comparing the reference group (the “no diploma” group) with other education groups: positive and significant differences are displayed in bold, and negative and significant differences are displayed in italic. Source: INCA-3 (2014–2015)

than others, Table 3 replicates the baseline regression model for several dependent variables relating to global diet (daily energy intake, UPF rate), risky food/beverage intakes (sweet drinks, sweets, and snack intake), and macronutrient composition of the diet (sugar, fat and protein intake). We reveal that, compared with individuals without

Table 2 Regression of nutritional status on education groups, meat consumption, and covariates

	BMI (kg/m ²)	Overweight/ obesity status (= 1)
Meat consumption (kg/month)	− 0.372 (0.374)	− 0.026 (0.032)
Technological or professional diploma (binary)	− 2.014* (1.116)	− 0.239*** (0.083)
Higher diploma (binary)	− 4.394*** (1.026)	− 0.413*** (0.079)
TechPro*MeatCons	0.383 (0.419)	0.047 (0.040)
HigherDip*MeatCons	0.867** (0.405)	0.095** (0.038)
Male (binary)	0.145 (0.364)	0.069* (0.040)
Aged 45–64 (binary)	1.635*** (0.372)	0.202*** (0.038)
Daily smoking (binary)	− 0.573* (0.341)	− 0.022 (0.040)
Alcohol consumption index (0-to-90 score)	0.011 (0.011)	0.001 (0.001)
Medium level of physical activity (binary)	− 1.120*** (0.359)	− 0.118*** (0.034)
High level of physical activity (binary)	− 1.559*** (0.484)	− 0.155** (0.060)
Medium level of sedentariness (binary)	− 0.345 (0.556)	0.014 (0.052)
High level of sedentariness (binary)	0.823 (0.523)	0.068 (0.051)
Lunch at home (binary)	0.174 (0.308)	0.044 (0.033)
Declared as vegetarian (binary)	0.201 (1.071)	0.047 (0.122)
Number of adults per household	0.428* (0.231)	0.045* (0.027)
Number of children per household	− 0.040 (0.160)	− 0.007 (0.017)
Season dummies	Yes	Yes
Urbanicity levels	Yes	Yes
Region dummies	Yes	Yes
Black's misreporting indexes	Yes	Yes
Constant	26.846*** (1.527)	0.394*** (0.141)
Observations	1,309	1,309
R-squared	0.237	0.190

Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo)

Standard errors are in parentheses. Levels of significance of fitted coefficients: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: INCA-3 (2014–2015)

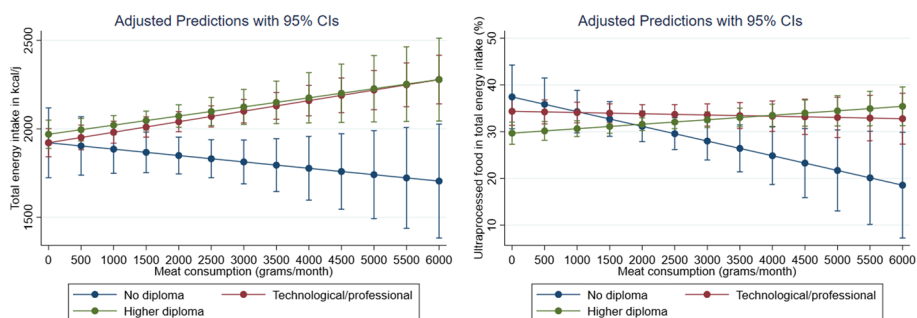


Fig. 3 Fitted diet indicators across education groups. *Notes* Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black’s index of under and overreporting. When total energy intake is used as dependent variable, we also control for the basal energy requirements of individuals. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014–2015)

a diploma, the most educated individuals with a high level of meat consumption tended to have a higher daily energy intake (88 kcal for each extra kg of meat per month, $p < 0.1$), as well as higher daily intake of UPF (4 percentage points for each extra kg of meat, $p < 0.01$), sweet drinks (58 g for each extra kg of meat, $p < 0.01$), sweets (10 g for each extra kg of meat, $p < 0.1$), sugar (13 g for each extra kg of meat, $p < 0.01$), and protein (4 g for each extra kg of meat, $p < 0.05$).⁷ Note that the lower significance observed for daily energy intake and intake of sweets, and the non-significance regarding snack and fat intake, might be due to an under-reporting bias that tends to be larger among the least educated and the most corpulent individuals, and that disproportionately concerns out-of-home food consumption and snacking (Poslusna et al. 2009; Archer et al. 2013).

Figures 3, 4, and 5 plot the fitted marginal effects (at the mean point) from Table 3 for each education group. Each figure (except for snacks and protein intake) shows a clear opposition between the least and the most educated individuals, which is highly consistent with our BMI-based findings. Indeed, it appears that among individuals without a diploma, eating less meat is positively and significantly associated with daily energy intake, and intake of UPF, sweet drinks, sweets, sugar, and fat, whereas the opposite is true for more educated individuals. Regarding snacks and protein intake, Figs. 2 and 3 indicate similar trends across education groups. However, for higher levels of meat consumption, the level of protein intake (as well as intake of snacks) is significantly lower among individuals without diploma.⁸

Finally, alternative estimates based on a discrete measurement of educational attainment (a score varying from 1 to 12) confirmed most previous findings from Table 2 and 3; i.e., higher positive associations between meat consumption and BMI, overweight status, UPF intake, sweet drink intake, and sugar intake among individuals with higher educational attainment than among less educated individuals (Table 4 in the Appendix).

⁸ This result echoes the ANSES (2017) report, which concludes that meat is a major source of protein for less educated individuals, while more educated individuals have a higher propensity to consume more diversified diet with alternative sources of proteins such as dairy products, legumes, and other plant proteins.

⁷ Results based on income and occupational classifications were less significant (available upon request).

Table 3 Regression of diet, unhealthy food intake, and macronutrient consumption on education, meat consumption, and covariates

	Diet		Unhealthy food intake			Macronutrient composition			
	Energy intake (Kcal/day)	UPF intake (% energy intake)	Sweet drinks intake (g/day)	Sweets intake (g/day)	Snacks intake (g/day)	Sugar intake (g/day)	Fat intake (g/day)	Protein intake (g/day)	
Meat consumption (kg/month)	0.112 (101.943)	- 3.070 (3.806)	2.587 (60.433)	- 0.959 (12.570)	- 8.158 (18.269)	- 6.199 (9.351)	3.032 (4.627)	1.270 (4.189)	
Technological or professional diploma (binary)	48.213 (105.642)	- 7.750** (3.788)	- 72.790 (46.734)	3.659 (13.041)	- 4.710 (17.401)	- 5.356 (10.021)	2.481 (4.353)	- 2.682 (4.329)	
Higher diploma (binary)	- 36.099 (39.948)	- 3.146** (1.419)	- 44.024*** (16.426)	- 8.994* (5.181)	- 17.302*** (6.449)	- 9.931*** (3.415)	- 0.582 (1.808)	3.903** (1.594)	
TechPro*MeatCons	95.657** (42.557)	2.882* (1.578)	31.221 (23.571)	11.378* (5.934)	12.418 (7.912)	9.701*** (3.635)	2.276 (1.916)	2.540 (1.772)	
HigherDip*MeatCons	87.619* (46.234)	4.102*** (1.569)	58.424*** (20.463)	9.728* (5.825)	6.660 (6.645)	12.599*** (4.187)	3.129 (1.934)	3.743** (1.762)	
Basal metabolic rate (Kcal/day)	0.571*** (0.119)								
Male (binary)	266.293*** (67.744)	1.919 (1.174)	61.714*** (23.326)	31.036*** (6.204)	26.028*** (6.103)	27.548*** (3.583)	13.387*** (2.087)	16.930*** (1.853)	
Aged 45–64 (binary)	- 31.931 (47.233)	- 10.147*** (1.167)	- 123.657*** (23.052)	- 11.084* (5.818)	- 36.538*** (6.712)	- 10.276*** (3.416)	- 2.506 (1.965)	1.122 (1.680)	
Daily smoking (binary)	- 176.514*** (34.801)	3.068** (1.464)	64.834 (42.215)	- 17.422*** (5.423)	11.819* (6.556)	- 12.184*** (3.109)	- 4.621** (1.778)	- 6.386*** (1.338)	
Alcohol consumption index (0-to-90 score)	- 2.741* (1.520)	- 0.127*** (0.047)	- 3.235*** (1.223)	- 0.525*** (0.192)	0.085 (0.252)	- 0.565*** (0.158)	0.052 (0.068)	- 0.008 (0.057)	
Medium level of physical activity (binary)	120.764*** (46.311)	- 3.458*** (1.307)	- 22.112 (20.282)	3.689 (6.179)	- 5.492 (6.506)	1.637 (3.987)	4.351*** (2.009)	4.502*** (1.518)	
High level of physical activity (binary)	254.661*** (65.612)	- 4.229** (1.778)	36.201 (39.712)	9.082 (8.916)	9.941 (10.285)	12.966** (6.166)	8.022*** (2.791)	9.573*** (2.254)	

Table 3 (continued)

	Diet		Unhealthy food intake			Macronutrient composition		
	Energy intake (Kcal/day)	UPF intake (% energy intake)	Sweet drinks intake (g/day)	Sweets intake (g/day)	Snacks intake (g/day)	Sugar intake (g/day)	Fat intake (g/day)	Protein intake (g/day)
Medium level of sedentariness (binary)	- 57.517 (65.973)	2.233 (1.634)	36.342 (33.516)	2.490 (7.786)	11.197 (10.246)	1.928 (4.516)	- 2.640 (3.085)	- 1.107 (2.268)
High level of sedentariness (binary)	- 93.023 (70.400)	2.128 (1.687)	48.887 (31.634)	- 1.265 (8.185)	13.094 (10.066)	0.195 (4.412)	- 1.897 (3.398)	- 4.029 (2.538)
Lunch at home (binary)	- 19.073 (46.111)	- 1.387 (1.149)	75.070** (31.499)	- 6.272 (6.039)	- 5.803 (5.993)	2.798 (4.626)	0.245 (1.920)	- 2.903* (1.606)
Declared as vegetarian (binary)	120.713 (93.955)	3.245 (6.050)	- 20.766 (50.339)	1.821 (15.596)	- 39.772** (17.204)	- 2.867 (8.019)	11.127*** (4.221)	4.894 (3.633)
Number of adults per household	- 8.654 (23.674)	- 0.700 (0.716)	31.722** (14.254)	- 0.440 (3.290)	1.367 (4.568)	- 2.509 (1.801)	- 0.708 (1.150)	- 0.244 (1.019)
Number of children per household	- 4.036 (23.382)	- 1.228** (0.579)	- 33.862*** (9.694)	- 0.127 (2.279)	2.435 (3.536)	- 3.743** (1.455)	- 0.353 (0.779)	- 0.149 (0.821)
Season dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urbanicity levels	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Black's misreporting indexes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1,160.943*** (261.854)	40.773*** (5.070)	109.093 (124.777)	76.451*** (19.205)	75.062** (28.813)	101.577*** (12.167)	64.941*** (7.531)	78.395*** (8.771)
Observations	1,309	1,312	1,312	1,312	1,312	1,312	1,312	1,312
R-squared	0.535	0.210	0.173	0.241	0.176	0.334	0.401	0.560

Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Standard errors are in parentheses. Levels of significance of fitted coefficients: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: INCA-3 (2014–2015)

Discussion

Based on a representative sample of the French adult population, this study showed SES-specific trends regarding the association between meat consumption and several nutritional indicators. Although meat consumption was positively associated with BMI and risk of overweight status in upper-SES groups, this relationship tended to be inverted in low-SES groups. In other words, under-privileged individuals who ate less meat tended to have a higher BMI and a higher risk of being classified as overweight than their counterparts who ate more meat, and compared with other socioeconomic groups. These results were robust for several SES measurements, including educational attainment, household income, occupation, and an indicator of financial insecurity perception. To our knowledge, this study is the first to show opposite relationships between meat consumption and BMI between lower and higher socioeconomic groups.

Another important finding of the study is that associations between meat consumption and several indicators of diet quality may also depend on SES. For such outcomes, the difference across SES was especially noticeable when based on education groups. For the most educated adults, we consistently found that reduced meat consumption was associated with lower consumption of UPF, as well as lower consumption of sweet drinks and sugar intake. In contrast, reduced meat consumption among individuals without a diploma was associated with a lower diet quality, which may explain why reduced meat consumption among lower social groups was positively correlated with BMI and overweight status. Unhealthy plant-based foods such as sweets and highly processed foods are generally cheaper and more accessible than healthy plant-based foods such as fresh fruit and vegetables or protein sources such as fish, dairy products or legumes, which may be used to compensate for reduced meat consumption (Vandevijvere et al. 2020). In France, the energy density of the food consumed decreases with the educational level of individuals (ANSES 2017). Hence, it is not surprising that poorly educated individuals are more likely to have diets rich in UPF and sugar when they consume less meat in a globalized context of the abundance of affordable energy-dense and ultra-palatable food. Several subfactors highly associated with low educational attainment, such as poorer nutritional literacy, decreased ability to understand nutritional labeling, or simply searching for a better energy(pleasure)/cost ratio, may contribute to explaining such risky feeding behaviors. By contrast, more educated individuals with greater nutritional knowledge and interest might be more successful at composing healthier diets in a context of reduced meat consumption.

Our data may contribute to revealing a paradox regarding meat intake that opposes patterns in traditional affluent societies, where reduced meat intake has been associated with a lower prevalence of overweight and obesity because of the low energy density of the available food (cereals, pulses, vegetables, and fruit), as compared with modern industrialized food environments, where reduced meat intake tends to be associated with greater consumption of energy-dense, ultra-palatable, low-protein foods (Steele et al. 2018). In the overall French population, people with high consumption of unprocessed food and low consumption of UPF exhibited greater consumption of meat and a better diet quality (Salomé et al. 2021). Through our application on the French population, we suggest that such a protein paradox might also appear within modern societies given the strong heterogeneity in their food environments and preferences, both

factors being highly correlated with individual SES. Indeed, in high-income countries like France, low-SES populations disproportionately live in obesogenic areas where UPF is highly promoted and fresh food is less accessible (Coutinho et al. 2023; Giskes et al. 2011). Furthermore, individuals living in poverty contexts tend to prefer to maximize their present satisfaction by consuming high-fat, high-sugar food and beverages perceived as palatable (qualified as “short-term low-risk strategies”) rather than invest in future and uncertain health-based satisfaction through suitable food intake restrictions and regular physical exercise (qualified as “long-term high-risk strategies”) (Levine 2015). Hence, in a speculative context of meat scarcity leading to (slightly) reduced meat consumption (e.g., due to the introduction of a tax policy or legal restrictions on the meat market), low-SES individuals may react differently than more privileged individuals. Although the latter might be more willing to invest in their health by choosing appropriate and available meat alternatives, the former might offset a decrease in meat-based protein by an increase in UPF and sugar intakes instead of expensive/uncommon plant-based protein preparations, leading to a calorie surplus and an increase in BMI.

Policy implications

Potential opposite nutritional impacts of a meat reduction in diet between lower and higher socioeconomic groups have important policy implications and should be seriously considered by governments that plan to regulate the meat market for public health purposes (e.g., through the introduction of tax or quality norms to increase meat prices and reduce its average consumption). Our results question the expected reduction in health expenditures that previous cohort studies suggested. In fact, a reduction in meat intake might accentuate the epidemic of obesity among low-SES individuals and increase its economic burden.

Likewise, the potential asymmetry in meat alternatives across SES is an issue that policymakers should consider from a food and protein transition perspective, especially for governments planning to reduce the food-related carbon footprint of their populations. Indeed, if a significant proportion of previous meat consumption is replaced by UPF, the expected ecological benefits of low-meat diets could be reduced (García et al. 2023); although red meat remains a very high contributor to greenhouse gas emissions regardless of UPF consumption levels (Kesse-Guyot et al. 2023; Perraud et al. 2023).

Consequently, our results emphasize the importance for policymakers to implement nutrition education programs to counter potential negative externalities of the protein transition, targeting underprivileged settings. For instance, conditional cash transfers including health check-ups and nutritional training for beneficiaries demonstrated protective effects against weight gain, independent of the amount of the cash transfer provided (Levasseur 2019). Adapting this type of program to protein transition issues may therefore help to sensitize and train under-privileged households to consume balanced and healthy plant-based diets.

Furthermore, important public investments in the development of plant-based foods (e.g., legume- and soy-based products) are also needed to improve the economic and geographic accessibility of plant proteins, as well as their sociocultural acceptability (Fresán et al. 2020; Magrini et al. 2017). For instance, some governments such as that of Denmark have already started to massively invest several tens of millions of dollars in

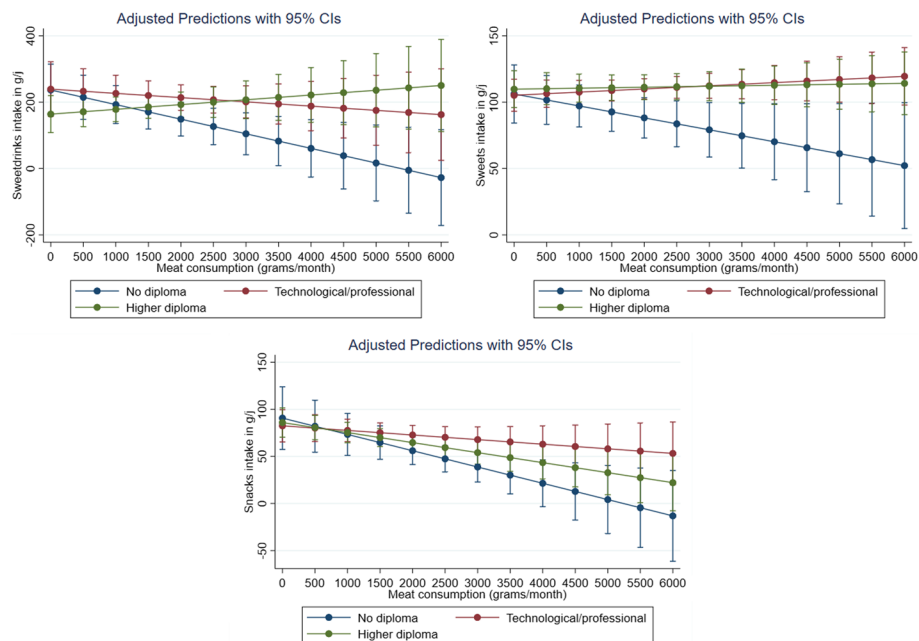


Fig. 4 Fitted risky food intakes across education groups. *Notes* Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014–2015)

this sector to increase the availability of plant-based options for consumers.⁹ In addition, information campaigns on plant proteins, such as that run by the FAO in 2016, have shown a greater impact on pulse consumption among low-income individuals compared with that wealthier individuals in France (Badji et al. 2023).

Limitations and research perspectives

Our study originally questions the generalized beneficial health impacts of the protein transition by first demonstrating potential socioeconomic heterogeneity in the association between meat intake and BMI. However, this study is not without limitations. The first limitation of the study relies on the cross-sectional nature of the data, which does not allow for robust identification of causal effects because of potential unobserved heterogeneity. To surpass this limitation and confirm SES-specific nutritional effects in the protein transition, experiments or observational studies using longitudinal data combined with endogeneity-correction tools (e.g., instrumental variables strategy) should be implemented in future research. A second limitation of the study relies on the lack of clarity regarding the intrinsic motivations related to SES that exactly affect food choice (e.g., health knowledge, confidence in the future, budget restrictions, and cultural patterns). Hence, further studies should also more deeply investigate individuals' motivations behind food choices (i.e., meat substitution strategies).

⁹ <https://foodnationdenmark.com/news/denmark-invests-over-eur-90-million-in-fund-for-development-of-plant-based-foods/>

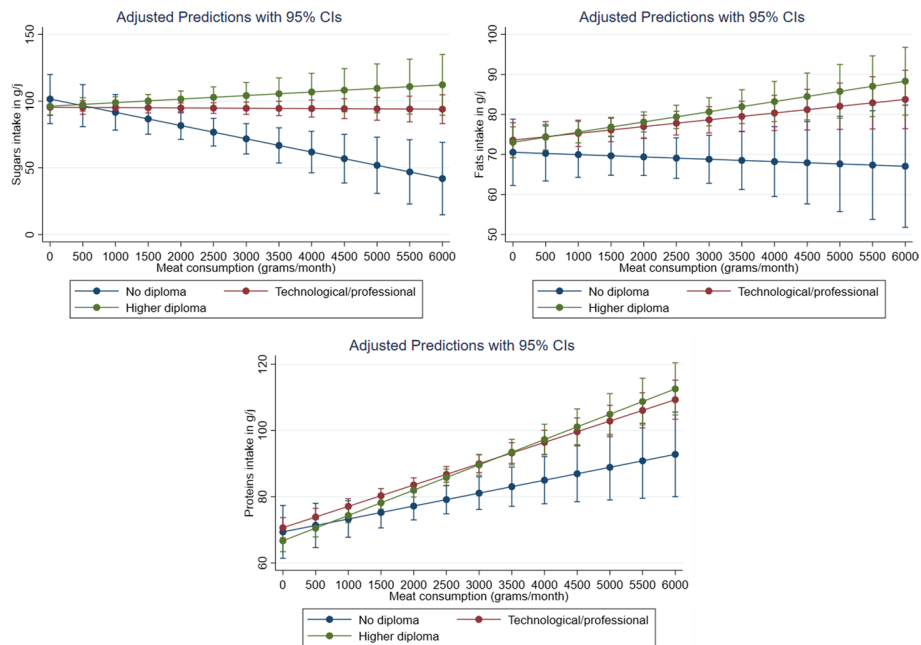


Fig. 5 Fitted macronutrient intakes across education groups. *Notes* Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black’s index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014–2015)

Appendix

See Figs. 6, 7, and 8 and Table 4.

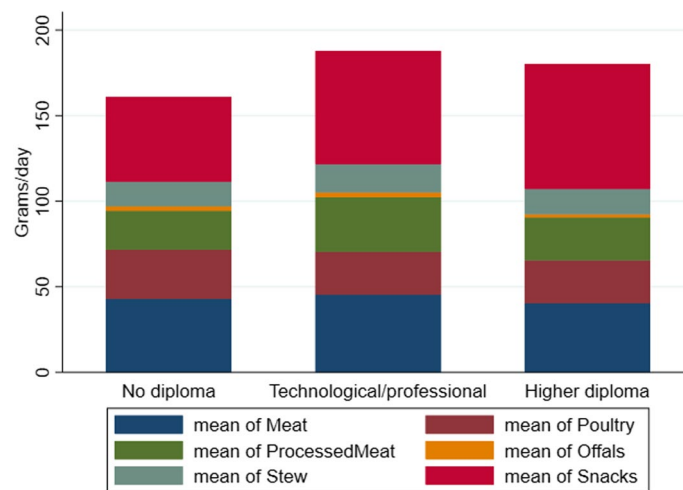


Fig. 6 Types of meat according to education groups. *Notes* Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). The meat category includes beef, pork, and lamb. The processed meat category includes sausages, terrines, and other mixtures. The snack category includes dishes that may partially include meat such as pizza, burgers, quiches, and sandwiches. The stew category includes dishes that partially include meat in sauce. Source: INCA-3 (2014–2015)

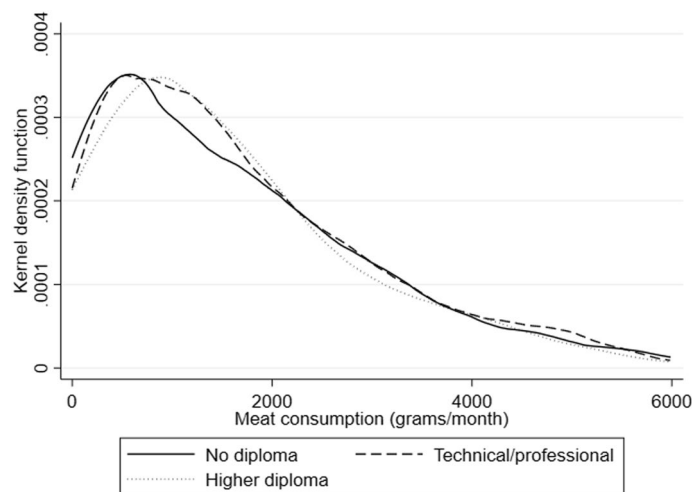


Fig. 7 Distribution of meat consumption across education groups. *Notes* Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Source: INCA-3 (2014–2015)

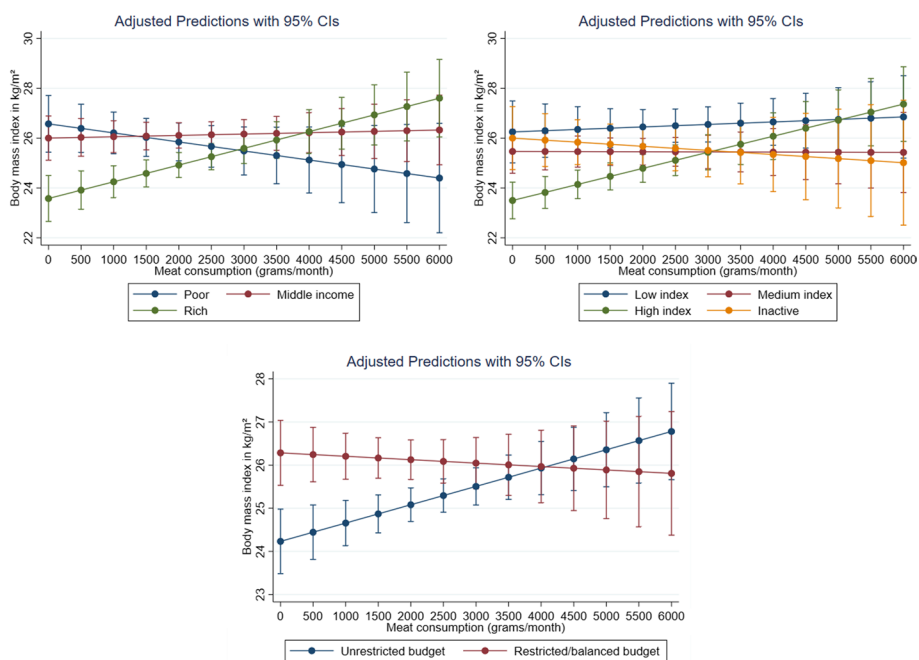


Fig. 8 Adjusted regressions of BMI on meat consumption by household income groups, occupation groups, and economic insecurity perception. *Notes* Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Estimates are adjusted by age, gender, smoking, alcohol consumption, physical activity, sedentariness, number of adults and children in the household, lunch place, vegetarian diet declaration, season of survey, urbanicity, region, and Black's index of under and overreporting. Confidence intervals (CIs) are fixed at the 95% level. Source: INCA-3 (2014–2015)

Table 4 Regression of all dependent variables on discrete education index, meat consumption, and covariates

	BMI (kg/m ²)	Energy intake (Kcal/day)	UPF intake (% total energy intake)	Sweet drinks intake (g/day)	Sweets intake (g/day)	Snacks intake (g/day)	Sugar intake (g/day)	Fat intake (g/day)	Protein intake (g/day)
Meat consumption (kg/month)	- 0.909* (0.470)	- 12.452 (41.864)	- 3.471** (1.406)	- 80.317*** (27.754)	- 5.585 (5.370)	- 8.678 (7.295)	- 11.216*** (3.648)	- 1.062 (2.022)	3.662** (1.650)
Diploma level (discrete)	- 0.600*** (0.123)	3.127 (11.425)	- 1.206*** (0.375)	- 19.012*** (5.644)	- 0.019 (1.582)	- 0.181 (2.106)	- 1.002 (1.194)	0.206 (0.487)	- 0.529 (0.493)
DiplomaLevel*MeatCons	0.132** (0.051)	7.288 (5.230)	0.423*** (0.158)	9.343*** (3.016)	0.753 (0.644)	- 0.002 (0.814)	1.385*** (0.472)	0.360 (0.231)	0.379* (0.206)
Basal metabolic rate (Kcal/day)		0.553*** (0.118)							
Male (binary)	0.203 (0.361)	273.758*** (67.836)	2.038* (1.170)	63.224*** (23.089)	31.244*** (6.186)	26.678*** (6.189)	27.442*** (3.537)	13.433*** (2.075)	17.057*** (1.864)
Aged 45–64 (binary)	1.693*** (0.357)	- 45.353 (48.676)	- 10.508*** (1.248)	- 130.243*** (23.138)	- 12.633** (5.882)	- 37.469*** (6.660)	- 11.226*** (3.519)	- 2.825 (1.992)	0.695 (1.711)
Daily smoking (binary)	- 0.585* (0.349)	- 174.212*** (34.689)	3.016** (1.501)	63.956 (42.132)	- 17.181*** (5.396)	12.484* (6.549)	- 12.239*** (3.128)	- 4.418** (1.788)	- 6.272*** (1.359)
Alcohol consumption index (0-to-90 score)	0.010 (0.012)	- 2.597* (1.533)	- 0.122** (0.048)	- 3.227*** (1.236)	- 0.503** (0.194)	0.101 (0.254)	- 0.554*** (0.157)	0.047 (0.068)	- 0.008 (0.058)
Medium level of physical activity (binary)	- 1.025*** (0.368)	128.390*** (47.968)	- 3.046** (1.324)	- 15.997 (20.950)	4.843 (6.069)	- 3.665 (6.426)	1.844 (4.059)	4.615** (1.998)	4.979*** (1.563)
High level of physical activity (binary)	- 1.551*** (0.488)	254.689*** (65.372)	- 4.048** (1.779)	37.087 (40.400)	9.191 (8.881)	9.476 (10.404)	13.575** (6.256)	7.921*** (2.753)	9.579*** (2.254)
Medium level of sedentariness (binary)	- 0.356 (0.550)	- 57.760 (66.712)	2.201 (1.637)	35.716 (33.960)	2.456 (7.798)	11.400 (10.096)	1.717 (4.490)	- 2.505 (3.116)	- 0.994 (2.291)
High level of sedentariness (binary)	0.746 (0.518)	- 88.800 (71.272)	2.041 (1.683)	46.857 (31.547)	- 0.921 (8.269)	13.352 (9.917)	0.491 (4.404)	- 1.792 (3.421)	- 4.043 (2.563)
Lunch at home (binary)	0.157 (0.321)	- 27.106 (47.061)	- 1.690 (1.167)	71.768** (30.851)	- 7.389 (6.022)	- 7.007 (6.099)	2.172 (4.656)	0.178 (1.927)	- 3.108* (1.645)

Table 4 (continued)

	BMI (kg/m ²)	Energy intake (Kcal/day)	UPF intake (% total energy intake)	Sweet drinks intake (g/day)	Sweets intake (g/day)	Snacks intake (g/day)	Sugar intake (g/day)	Fat intake (g/day)	Protein intake (g/day)
Declared as vegetarian (binary)	0.319 (1.088)	128.287 (87.165)	3.395 (6.199)	- 11.574 (48.006)	2.823 (15.541)	- 38.430** (15.899)	- 2.561 (7.625)	11.500*** (4.264)	5.157 (3.862)
Number of adults per household	0.418* (0.236)	- 10.743 (23.438)	- 0.772 (0.725)	32.769** (15.237)	- 0.817 (3.281)	0.600 (4.491)	- 2.594 (1.824)	- 0.591 (1.115)	- 0.195 (1.009)
Number of children per household	- 0.024 (0.158)	- 5.320 (23.848)	- 1.212** (0.563)	- 33.326*** (9.510)	- 0.250 (2.369)	2.279 (3.510)	- 3.850*** (1.458)	- 0.428 (0.781)	- 0.181 (0.821)
Season dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urbanicity levels	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Black's misreporting indexes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	28.803*** (1.600)	1,202,091 *** (273,884)	46.191 *** (5.104)	236,588** (113,399)	80,602*** (19,983)	74,067** (31,437)	105,809*** (13,005)	65,950*** (7,696)	82,414*** (9,459)
Observations	1,309	1,309	1,312	1,312	1,312	1,312	1,312	1,312	1,312
R-squared	0.230	0.530	0.206	0.173	0.236	0.170	0.328	0.399	0.555

Estimates are weighted using the survey recommendations to guarantee the representativeness of the sample. Lactating and pregnant women were excluded as well as children (< 18 yo) and the elderly (> 65 yo). Standard errors are in parentheses. Levels of significance of fitted coefficients: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: INCA-3 (2014–2015)

Abbreviations

BMI	Body mass index
INCA3	French National Individual Survey on Food Consumption, round 3
RCT	Randomized controlled trial
SES	Socioeconomic status
UPF	Ultra-processed food

Acknowledgements

The authors thank the French Public Health Agency (ANSES) for freely and publicly providing the INCA 3 database.

Author contributions

PL performed conceptualization, data curation, formal analysis, funding acquisition, methodology, software, visualization, and writing—original draft preparation; OD provided conceptualization, literature review, funding acquisition, and writing—original draft preparation; FM analyzed conceptualization, methodology, and writing—review and editing; ID approved conceptualization and writing—review and editing.

Funding

This research is supported by funds provided by the French Research Agency (ANR) under the Grant Number 11001692.

Availability of data and materials

Available on: <https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-3/>

Declarations

Competing interests

Each author has no conflict of interest to declare. This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving research study participants were approved by the ethics committee of ANSES. Written informed consent was obtained from all surveyed participants. Please refer to the survey website and related documents and data, available on: <https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-3/>.

Received: 8 August 2023 Revised: 19 December 2023 Accepted: 12 January 2024

Published online: 30 January 2024

References

- ANSES (2016) Actualisation des repères du PNNS: révision des repères de consommation alimentaire : avis de l'ANSES, rapport d'expertise collective. Anses éditions, Maisons-Alfort
- ANSES (2017) INCA 3 : Evolution des habitudes et modes de consommation, de nouveaux enjeux en matière de sécurité sanitaire et de nutrition : avis de l'ANSES, Rapport d'expertise collective. Anses édition scientifiques, Maisons-Alfort
- Archer E, Hand GA, Blair SN (2013) Validity of U.S. nutritional surveillance: National Health and Nutrition Examination Survey caloric energy intake data, 1971–2010. *PLoS ONE* 8:e76632. <https://doi.org/10.1371/journal.pone.0076632>
- Badji I, Caillavet F, Amiot MJ (2023) Changes in French purchases of pulses during an FAO awareness campaign. *Front Nutr* 9
- Bonnefond C, Clément M (2014) Social class and body weight among Chinese urban adults: The role of the middle classes in the nutrition transition. *Soc Sci Med* 112C:22–29. <https://doi.org/10.1016/j.socscimed.2014.04.021>
- Bourdieu P (2002) The forms of capital. In: Biggart NW (Ed) *Readings in economic sociology*. Blackwell Publishers Ltd, pp 280–291. <https://doi.org/10.1002/9780470755679.ch15>
- Boutron-Ruault M-C, Mesrine S, Pierre F (2017) 12 - Meat consumption and health outcomes. In: Mariotti F (Ed), *Vegetarian and plant-based diets in health and disease prevention*. Academic Press, pp 197–214. <https://doi.org/10.1016/B978-0-12-803968-7.00012-5>
- Butler TL, Fraser GE, Beeson WL, Knutsen SF, Herring RP, Chan J, Sabaté J, Montgomery S, Haddad E, Preston-Martin S, Bennett H, Jaceldo-Siegl K (2008) Cohort Profile: the adventist health study-2 (AHS-2). *Int J Epidemiol* 37:260–265. <https://doi.org/10.1093/ije/dym165>
- Clément M (2017) The income-body-size gradient among Chinese urban adults: a semiparametric analysis. *China Econ Rev* 44:253–270
- Coutinho SR, Andersen OK, Lien N, Gebremariam MK (2023) Neighborhood deprivation, built environment, and overweight in adolescents in the city of Oslo. *BMC Public Health* 23:812. <https://doi.org/10.1186/s12889-023-15261-2>
- Crédoc, (2016) *Enquête sur les comportements et consommations alimentaires en France (CCAF)*. Consommation et modes de vie, Paris
- Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip A (2021) Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat Food* 2:198–209. <https://doi.org/10.1038/s43016-021-00225-9>
- Daran B, Levasseur P (2022) Is overweight still a problem of rich in sub-Saharan Africa? Insights based on female-oriented demographic and health surveys. *World Dev Perspect* 25:100388. <https://doi.org/10.1016/j.wdp.2021.100388>
- Darmon N (2008) Le gradient social de l'obésité se creuse en France – Sait-on pourquoi ? *OCL* 15:46–52. <https://doi.org/10.1051/ocl.2008.0161>
- Darmon N, Drewnowski A (2008) Does social class predict diet quality? *Am J Clin Nutr* 87:1107–1117. <https://doi.org/10.1093/ajcn/87.5.1107>

- Dinu M, Abbate R, Gensini GF, Casini A, Sofi F (2017) Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies. *Crit Rev Food Sci Nutr* 57:3640–3649. <https://doi.org/10.1080/10408398.2016.1138447>
- Dubuisson C, Dufour A, Carrillo S, Drouillet-Pinard P, Havard S, Volatier J-L (2019) The Third French Individual and National Food Consumption (INCA3) Survey 2014–2015: method, design and participation rate in the framework of a European harmonization process. *Public Health Nutr* 22:584–600. <https://doi.org/10.1017/S1368980018002896>
- Dussiot A, Fouillet H, Perraud E, Salomé M, Huneau J-F, Kesse-Guyot E, Mariotti F (2022) Nutritional issues and dietary levers during gradual meat reduction: a sequential diet optimization study to achieve progressively healthier diets. *Clin Nutr* 41:2597–2606. <https://doi.org/10.1016/j.clnu.2022.09.017>
- Fresán U, Errendal S, Craig WJ (2020) Influence of the socio-cultural environment and external factors in following plant-based diets. *Sustainability* 12:9093. <https://doi.org/10.3390/su12219093>
- García S, Pastor R, Monserrat-Mesquida M, Álvarez-Álvarez L, Rubín-García M, Martínez-González MÁ, Salas-Salvadó J, Corella D, Fitó M, Martínez JA, Tojal-Sierra L, Wärnberg J, Vioque J, Romaguera D, López-Miranda J, Estruch R, Tinahones FJ, Santos-Lozano JM, Serra-Majem L, Cano-Ibañez N, Pintó X, Delgado-Rodríguez M, Matía-Martin P, Vidal J, Vázquez C, Daimiel L, Ros E, Buil-Cosiales P, Martínez-Rodríguez MÁ, Coltell O, Castañer O, García-Ríos A, Barceló C, Gómez-Gracia E, Zulet MÁ, Konieczna J, Casas R, Massó-Guijarro P, Goicolea-Güemez L, Bernal-López MR, Bes-Rastrollo M, Shyam S, González JI, Zomeño MD, Peña-Orihuela PJ, González-Palacios S, Toledo E, Khoury N, Perez KA, Martín-Sánchez V, Tur JA, Bouzas C (2023) Ultra-processed foods consumption as a promoting factor of greenhouse gas emissions, water, energy, and land use: a longitudinal assessment. *Sci Total Environ* 891:164417. <https://doi.org/10.1016/j.scitotenv.2023.164417>
- Giskes K, van Lenthe F, Avendano-Pabon M, Brug J (2011) A systematic review of environmental factors and obesogenic dietary intakes among adults: Are we getting closer to understanding obesogenic environments? *Obes Rev* 12:e95–e106. <https://doi.org/10.1111/j.1467-789X.2010.00769.x>
- Habumugisha T, Engebretsen IMS, Måren IE, Kaiser CWM, Dierkes J (2023) Reducing meat and/or dairy consumption in adults: a systematic review and meta-analysis of effects on protein intake, anthropometric values, and body composition. *Nutr Rev*. <https://doi.org/10.1093/nutrit/nuad055>
- Kesse-Guyot E, Allès B, Brunin J, Fouillet H, Dussiot A, Berthy F, Perraud E, Hercberg S, Julia C, Mariotti F, Deschasaux-Tanguy M, Srour B, Lairon D, Pointereau P, Baudry J, Touvier M (2023) Environmental impacts along the value chain from the consumption of ultra-processed foods. *Nat Sustain* 6:192–202. <https://doi.org/10.1038/s41893-022-01013-4>
- Le LT, Sabaté J (2014) Beyond meatless, the health effects of vegan diets: findings from the adventist cohorts. *Nutrients* 6:2131–2147. <https://doi.org/10.3390/nu6062131>
- Levasseur P (2015) Causal effects of socioeconomic status on central adiposity risks: evidence using panel data from urban Mexico. *Soc Sci Med* 136–137:165–174. <https://doi.org/10.1016/j.socscimed.2015.05.018>
- Levasseur P (2019) Can social programs break the vicious cycle between poverty and obesity? Evidence from urban Mexico. *World Dev* 113:143–156. <https://doi.org/10.1016/j.worlddev.2018.09.003>
- Levine JA (2015) Solving obesity without addressing poverty: fat chance. *J Hepatol* 63:1523–1524. <https://doi.org/10.1016/j.jhep.2015.07.029>
- Magrini M-B, Anton M, Cholez C, Duc G, Hellou G, Jeuffroy M-H, Meynard J-M, Pelzer É, Voisin A-S, Walrand S (2017) Transition vers des systèmes agricole et agroalimentaire durables: quelle place et qualification pour les légumineuses à graines? *Revue Française De Socio-Économie* 18:53–75. <https://doi.org/10.3917/rfse.018.0053>
- Maillot M, Darmon N, Lafay L, Drewnowski A (2007) Nutrient-dense food groups have high energy costs: an econometric approach to nutrient profiling. *J Nutr* 137:1815–1820
- Méjean C, Recchia D (2022) Urban foodscape and its relationships with diet and health outcomes. *Proc Nutr Soc* 81:272–278. <https://doi.org/10.1017/S0029665122002701>
- Mekonnen M, Hoekstra AY (2010) The green, blue and grey water footprint of animals and animal products
- Mollier P (2019) Régime moyen d'un français. INRAE, Paris
- Monnery Patris S, Laugel V, Poquet D, Chamberon S (2019) Nouveaux aliments à base de légumineuses: les consommateurs sont-ils prêts? *Innovations Agronomiques* 74:183–191. <https://doi.org/10.15454/15fta3>
- Mozaffarian D, Hao T, Rimm EB, Willett WC, Hu FB (2011) Changes in diet and lifestyle and long-term weight gain in women and men [WWW Document]. <https://doi.org/10.1056/NEJMoa1014296>
- Perraud E, Wang J, Salomé M, Mariotti F, Kesse-Guyot E (2023) Dietary protein consumption profiles show contrasting impacts on environmental and health indicators. *Sci Total Environ* 856:159052. <https://doi.org/10.1016/j.scitotenv.2022.159052>
- Poslusna K, Ruprich J, de Vries JHM, Jakubikova M, van't Veer, P. (2009) Misreporting of energy and micronutrient intake estimated by food records and 24 hour recalls, control and adjustment methods in practice. *Br J Nutr* 101(Suppl 2):S73–85. <https://doi.org/10.1017/S0007114509990602>
- Rosell M, Appleby P, Spencer E, Key T (2006) Weight gain over 5 years in 21 966 meat-eating, fish-eating, vegetarian, and vegan men and women in EPIC-Oxford. *Int J Obes* 30:1389–1396. <https://doi.org/10.1038/sj.ijo.0803305>
- Salomé M, de Gavelle E, Dufour A, Dubuisson C, Volatier J-L, Fouillet H, Huneau J-F, Mariotti F (2020) Plant-protein diversity is critical to ensuring the nutritional adequacy of diets when replacing animal with plant protein: observed and modeled diets of French adults (INCA3). *J Nutr* 150:536–545. <https://doi.org/10.1093/jn/nxz252>
- Salomé M, Arrazat L, Wang J, Dufour A, Dubuisson C, Volatier J-L, Huneau J-F, Mariotti F (2021) Contrary to ultra-processed foods, the consumption of unprocessed or minimally processed foods is associated with favorable patterns of protein intake, diet quality and lower cardiometabolic risk in French adults (INCA3). *Eur J Nutr* 60:4055–4067. <https://doi.org/10.1007/s00394-021-02576-2>
- Satija A, Bhupathiraju SN, Rimm EB, Spiegelman D, Chiuve SE, Borgi L, Willett WC, Manson JE, Sun Q, Hu FB (2016) Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies. *PLoS Med* 13:e1002039. <https://doi.org/10.1371/journal.pmed.1002039>
- Satija A, Bhupathiraju SN, Spiegelman D, Chiuve SE, Manson JE, Willett W, Rexrode KM, Rimm EB, Hu FB (2017) Healthful and unhealthful plant-based diets and the risk of coronary heart disease in U.S. adults. *J Am Coll Cardiol* 70:411–422. <https://doi.org/10.1016/j.jacc.2017.05.047>

- Satija A, Malik V, Rimm EB, Sacks F, Willett W, Hu FB (2019) Changes in intake of plant-based diets and weight change: results from 3 prospective cohort studies. *Am J Clin Nutr* 110:574–582. <https://doi.org/10.1093/ajcn/nqz049>
- Scarborough P, Clark M, Cobiac L, Papier K, Knuppel A, Lynch J, Harrington R, Key T, Springmann M (2023) Vegans, vegetarians, fish-eaters and meat-eaters in the UK show discrepant environmental impacts. *Nat Food* 4:565–574. <https://doi.org/10.1038/s43016-023-00795-w>
- Spencer EA, Appleby PN, Davey GK, Key TJ (2003) Diet and body mass index in 38 000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans. *Int J Obes* 27:728–734. <https://doi.org/10.1038/sj.ijo.0802300>
- Springmann M, Godfray HCJ, Rayner M, Scarborough P (2016) Analysis and valuation of the health and climate change cobenefits of dietary change. *PNAS* 113:4146–4151. <https://doi.org/10.1073/pnas.1523119113>
- Springmann M, Mason-D’Croz D, Robinson S, Wiebe K, Godfray HCJ, Rayner M, Scarborough P (2018) Health-motivated taxes on red and processed meat: a modelling study on optimal tax levels and associated health impacts. *PLoS ONE* 13:e0204139. <https://doi.org/10.1371/journal.pone.0204139>
- Steele EM, Raubenheimer D, Simpson SJ, Baraldi LG, Monteiro CA (2018) Ultra-processed foods, protein leverage and energy intake in the USA. *Public Health Nutr* 21:114–124. <https://doi.org/10.1017/S1368980017001574>
- Vandevijvere S, Pedroni C, De Ridder K, Castetbon K (2020) The cost of diets according to their caloric share of ultraprocessed and minimally processed foods in Belgium. *Nutrients* 12:E2787. <https://doi.org/10.3390/nu12092787>
- Vergnaud A-C, Norat T, Romaguera D, Mouw T, May AM, Travier N, Luan J, Wareham N, Slimani N, Rinaldi S, Couto E, Clavel-Chapelon F, Boutron-Ruault M-C, Cottet V, Palli D, Agnoli C, Panico S, Tumino R, Vineis P, Agudo A, Rodriguez L, Sanchez MJ, Amiano P, Barricarte A, Huerta JM, Key TJ, Spencer EA, Bueno-de-Mesquita B, Büchner FL, Orfanos P, Naska A, Trichopoulou A, Rohrmann S, Hermann S, Boeing H, Buijsse B, Johansson I, Hellstrom V, Manjer J, Wirfält E, Jakobsen MU, Overvad K, Tjonneland A, Halkjaer J, Lund E, Braaten T, Engeset D, Odysseos A, Riboli E, Peeters PH (2010) Meat consumption and prospective weight change in participants of the EPIC-PANACEA study. *Am J Clin Nutr* 92:398–407. <https://doi.org/10.3945/ajcn.2009.28713>
- WHO (2023) Red and processed meat in the context of health and the environment: many shades of red and green: information brief (No. ISBN: 978-92-4-007482-8). Nutrition and Food Safety (NFS)

Publisher’s Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.