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Improvement of diet sustainability with increased level of organic food in the diet: findings from the BioNutriNet cohort

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ABSTRACT

Background: Organic food consumption has steadily increased over the past decade in westernized countries.

Objective: The aim of this study, based on observational data, was to compare some sustainability features of diets from consumers with varying levels of organic food.

Methods: The diet sustainability among 29,210 participants of the NutriNet-Santé study was estimated using databases developed within the BioNutriNet project. Four dimensions (nutrition, environment, economy, and toxicology) of diet sustainability were assessed using: 1) nutritional indicators through dietary intakes and dietary scores, and BMI; 2) environmental indicators (greenhouse gas emissions, cumulative energy demand, and land occupation); 3) economic indicators via diet monetary costs; and 4) estimated daily food exposures to 15 pesticides. Adjusted means (95% CI) across weighted quintiles of organic food consumption in the diet were estimated via ANCOVA. Breakdown methods were used to disentangle the contribution of the production system (organic compared with conventional) from the dietary pattern in the variation of diet-related environmental impacts, monetary costs, and pesticide exposure, between the 2 extreme quintiles.

Results: Higher organic food consumption was associated with higher plant-food and lower animal-food consumption, overall nutritional quality (higher dietary scores), and lower BMI. Diet-related greenhouse-gas emissions, cumulative energy demand, and land occupation gradually decreased with increasing organic food consumption, whereas total diet monetary cost increased. Diet exposure to most pesticides decreased across quintiles.

Conclusions: Diets of high organic food consumers were generally characterized by strong nutritional and environmental benefits. The latter were mostly driven by the low consumption of animal-based foods, whereas the production system was responsible for the higher diet monetary costs, and the overall reduced dietary pesticide exposure. *Am J Clin Nutr* 2019;109:1173–1188.

Keywords: sustainability indicators, organic food consumption, dietary score, dietary greenhouse gas emissions, cumulative energy

demand, diet monetary cost, dietary pesticide exposure, observational data

Introduction

Current food-consumption patterns observed in developed countries raise major health and environmental concerns (1). Unhealthy diets are important risk factors for various chronic diseases (2). Moreover, food-system-related activities, from production to consumption, account for 20–30% of total greenhouse gas emissions (GHGEs), contributing significantly to climate change (3). Agricultural activities also negatively affect biodiversity, soil quality, and water quality, and involve high fossil energy consumption (4). In addition, chemicals used in

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Supplemental Materials 1–5 and Supplemental Figure 1 are available from the “Supplementary data” link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/ajcn/>.

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Abbreviations used: bw, body weight; CED, cumulative energy demand; CVUA, Chemisches und Veterinäruntersuchungsamt; EDI, estimated daily intake; GHGE, greenhouse gas emission; Org-FFQ, organic food-frequency questionnaire; Q, quintile.

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agriculture have potential harmful effects on consumers' and producers' health, through diverse routes of exposure including diet (5).

In this context, the FAO defined in 2010 sustainable diets as those "protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair, and affordable; nutritionally adequate, safe, and healthy; while optimizing natural and human resources" (1).

The considerable development of the organic food market (6), driven by health and environmental motives, reflects a high demand from consumers toward more sustainable production methods. The organic systems are often considered as more sustainable than their counterparts, as they include the nonuse of synthetic fertilizers and pesticides as well as the diversification of crops and livestock (7). In Europe, organic principles are framed by a specific and strict regulation (8), resulting in fewer or no pesticide residues (9, 10) as well as more nutritious compositions (9, 11, 12) in organic products than with conventional products. With regard to environmental aspects, organic food production is generally characterized by a higher energy efficiency than conventional food production (7, 13–15), a higher soil quality (16), and a higher plant and animal diversity (7, 15, 17–19). Nevertheless, potential effects of organic and conventional production in terms of GHGEs are similar (13, 19–21), whereas this type of production usually requires more land (per unit of food produced) (13, 22). Regarding eutrophication, the existing comparative life cycle assessment methods on organic or conventional products do not allow the specific differences between the farming systems to be captured (23). Furthermore, organic food prices are generally higher than conventional food prices (24) for various reasons (e.g., more extensive practices, higher labor costs, lower productivity, less developed networks, or increased farmers' incomes).

Although some studies have investigated the sustainability of different food patterns in terms of nutritional quality and environmental impacts (25), few studies have assessed the differences between conventional and organic diets. These studies have primarily focused on individual components of diet sustainability based on few indicators (mostly environmental and nutritional), whereas the adoption of a multicriteria approach is of great importance to provide a comprehensive evaluation of diet sustainability.

Hence, the primary purpose of this study was to evaluate the sustainability of the diet of consumers with varying degree of organic consumption, using a broad range of indicators related to various sustainability dimensions (nutritional, environmental, economic, and toxicological aspects), in a large sample of French adults from the NutriNet-Santé study. Because organic food consumption has been strongly associated with healthier dietary behaviors in many studies (26–28), and in the NutriNet-Santé cohort (29, 30) in particular, we further attempted to identify the specific contribution of the dietary patterns and the production system (considered as independent variables) in the differences in diet-related impacts (considered as the dependent variable), observed between low- and high-organic-food consumers, through breakdown methods.

We aimed to address these 2 research questions on the basis of an original and multidisciplinary analysis of observed diets from a large sample of participants of the French NutriNet-Santé cohort. This cohort provides a large and comprehensive database,

unique worldwide, combining nutritional, environmental, economic, and toxicological indicators.

Methods and Data

Study population

The NutriNet-Santé study is a web-based cohort launched in May 2009 (31). Participants are Internet-using adult volunteers from the general French population. At inclusion and every year, participants complete a baseline set of self-administered questionnaires regarding socio-economic status, anthropometrics, lifestyle, physical activity, and dietary intakes. They are also invited to fill in complementary questionnaires on dietary behaviors, nutritional, and health status.

This study is conducted in accordance with the Declaration of Helsinki, and all procedures were approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB Inserm 0000388FWA00005831) and the Commission Nationale de l'Informatique et des Libertés (CNIL 908,450 and 909,216). Electronic informed consent was obtained from all participants.

Dietary intake assessment

Dietary intake was assessed using a self-administered semi-quantitative organic food-frequency questionnaire (Org-FFQ) from June to December 2014 (23). The Org-FFQ was based on a validated FFQ (32), to which a 5-point ordinal scale was added to measure the frequency of organic food consumption. More specifically, for each of the 264 items included in the questionnaire, participants were asked to provide their frequency of consumption and the quantity consumed during the previous year (33). In addition, for the 257 food and beverage items produced under the organic label, participants were also asked to answer the question, "How often was the product of organic origin?" by selecting 1 of the following 5 frequency modalities: never, rarely, half-of-time, often, or always. Organic food consumption was obtained by attributing the respective percentages, 0, 25, 50, 75, and 100, to the aforementioned modalities. Fuller details regarding the Org-FFQ and sensitivity analyses as regards the weighting have been published elsewhere (23).

The different food and beverage items were aggregated into 16 food groups. Values for nutrients were derived from a published ad hoc food composition database (34). Of note, the production system (organic compared with conventional) of the products was not taken into account when evaluating nutritional profiles.

Dietary scores

The overall dietary quality was evaluated using 2 indicators. The food-based Programme National Nutrition Santé Guideline Score (35) assesses adherence to the French official nutrition guidelines. We computed a modified Programme National Nutrition Santé Guideline Score (/13.5) by removing the physical activity component. The nutrient-based Probability of Adequate Nutrient Intake Diet (/100) (36) score measures the probability of adequate nutrient intake based on current nutrient reference

values. It is composed of 2 subscales: adequacy and moderation (see **Supplemental Material 1**).

Environmental impact assessment

The description of the environmental impact assessment in NutriNet-Santé has been detailed elsewhere (37). The environmental dimension was assessed per day at the farm level (i.e., conditioning, transport, processing, storage, and recycling were excluded from the analysis) by computing 3 indicators pertaining to the production of a given quantity of food product: the GHGEs measured as kg of CO₂ equivalents (CO₂-eq), the cumulative energy demand (CED) in MJ, and the land occupation expressed in m². Data were collected using the tool DIALECTE (38). Diet-related GHGEs, CED, and land occupation were obtained by multiplying the reported intake of each food item by its respective environmental indicator and conversion factor values, and summing over all food items consumed by the participant, while accounting for the production system (**Supplemental Material 2**).

Economic-related data assessment

Data on places of food purchase were collected in July 2014 through a complementary questionnaire, available during 6 months on the NutriNet-Santé platform, focusing on attitudes, intentions, and practices toward organic food. Food prices for each of the 264 food-frequency questionnaire items for every place of purchase proposed in the aforementioned questionnaire were based on mean price values obtained using the 2012 Kantar Worldpanel purchase database (39).

This home-scan data set is based on records of a French representative consumer panel of 20,000 households. Purchased quantities and expenditures were used to calculate mean prices of each of the 264 items depending on the product type (organic compared with conventional) and the site of purchase (superstores, supermarkets, specialized stores). Additional prices were collected by volunteers of the Bioconsom'acteurs' association as regards food groups supplied through short channels (e.g., local markets or associations supporting small farming). For each participant, the daily diet monetary cost (€/d) was then estimated by multiplying the quantities consumed (g/d) by the corresponding item prices (€/g) while accounting for cooking preparation and waste, and considering the production system. The proportion of the income (%) devoted to diet was also estimated by dividing the total diet monetary cost by the income reported by the participants.

Pesticide exposure assessment

The dimension of diet sustainability related to toxicology aspects was evaluated through the dietary exposure via plant food intakes—by far the most contaminated food groups (40)—to 15 available pesticides considering both their frequency of detection above the maximum residue levels when sufficient data were available and their acceptable daily intake. Contamination data were derived from the Chemisches und Veterinäruntersuchungsamt (CVUA) Stuttgart database (41). One hundred and eighty plant ingredients that were both important constituents of

the 264 food items and available in the CVUA database were attributed a contamination value in organic and conventional modes. For each pesticide, the estimated daily intake (EDI) (in µg/kg bw/d) under lower- and upper-bound scenarios was calculated using methods described by Nougadère et al. (42) (**Supplemental Material 3**).

Table 1 summarizes the different indicators of diet sustainability included in the study, and the respective determination procedures.

Statistical analyses

For this study, we retained NutriNet-Santé participants who completed the Org-FFQ between June and December 2014 ($N = 37,685$), with no missing covariates ($N = 37,305$), who were not detected as under- or over-reporters ($N = 35,196$), who were not living overseas to permit the computation of a weighting procedure described below ($N = 34,453$), and with available data regarding the place of purchase for the computation of the monetary cost of the diet, leaving a total sample of 29,210 participants (**Supplemental Figure 1**). In addition, in order to make our study sample more representative of the French population, for each gender, weighting was calculated using the iterative proportional fitting procedure according to 2009 national census reports (43) on age, occupational category, educational level, area of residence, presence of children (<18 y), and marital status. The covariate assessment is presented in **Supplemental Material 4**.

According to the proportion of organic food in their diet, participants were ranked and divided into weighted quintiles (Q_i). Participant characteristics across levels of organic food consumption (quintiles of proportion of organic food in the diet) are reported as means ± SDs. *P* values refer to tests for linear contrast for continuous variables or Mantel–Haenszel chi-square trend tests for categorical variables.

ANCOVA models were performed to evaluate the association between each sustainability indicator and the proportion of organic food in the diet, providing adjusted means (95% CI), using observed margins. An initial model was unadjusted. All adjusted models included the following confounding factors: age, gender, and total daily energy intake. Energy adjustment was conducted using the residual method for nutrient intake. Concerning dietary exposure to pesticides, the main model was further adjusted for the coverage of the diet. *P* values were estimated via linear contrast tests (corrected for multiple comparisons using a Bonferroni procedure).

Two-sided tests were used, and a *P* value of <0.05 was considered significant. Data management and statistical analyses were performed using SAS (version 9.4; SAS Institute, Inc.).

Breakdown of the effects

In order to differentiate the mutual contribution of dietary pattern and production system (independent variables) on diet monetary cost (dependent variable), we broke down the variation of the diet monetary cost between the 2 extreme quintile individuals (Q₁ and Q₅) into 3 components:

- (1) The “dietary pattern effect,” that is the difference between Q₁ and Q₅ that results from the difference in dietary

TABLE 1 Overview of the indicators included in the present study, NutriNet-Santé

Sustainability dimension measured by the indicator		Data sources	Aim/definition	Determination of the indicator
Dietary intakes	Nutrition-related dimension	NutriNet-Santé composition database (2014)	Measure of the absolute and relative intakes of main relevant food and nutrients	Calculation at the consumer level
Dietary scores	Nutrition-related dimension	NutriNet-Santé composition database (2014)	Measure of the consumption of a wide variety of foods and of the overall nutritional diet quality (including adequacy to French nutritional guidelines and reference values)	Calculation at the consumer level
BMI	Nutritional anthropometry dimension	NutriNet-Santé anthropometric questionnaire (2014)	Measure of overweight levels	Self-report
Greenhouse-gas emission	Environment-related dimension	Mostly DIALECTE database (2000–2015 with 50% of data collected after 2010) completed by data available in the literature	Measure of climate change	Computation of the indicator at the farm level, differentiating the food production systems (organic vs. conventional) and further allocations of economic, mass, cooking, and edibility factors to obtain impacts at the consumer level
Cumulative energy demand	Environment-related dimension	Mostly DIALECTE database (2000–2015 with 50% of data collected after 2010) completed by data available in the literature	Partial reflection of natural resource depletion	Computation of the indicator at the farm level, differentiating the food production systems (organic vs. conventional) and further allocations of economic, mass, cooking, and edibility factors to obtain impacts at the consumer level
Land occupation	Environment-related dimension	Mostly DIALECTE database (2000–2015 with 50% of data collected after 2010) completed by data available in the literature	Reflection of resource depletion and biodiversity	Computation of the indicator at the farm level, differentiating the food production systems (organic vs. conventional) and further allocations of economic, mass, cooking, and edibility factors to obtain impacts at the consumer level
Diet monetary costs	Economic-related dimension	Kantar-World panel purchase database (2012) completed by ~2000 prices collected from short supply chains by Bioconsum'acteurs' members (fall 2014 and spring 2015)	Assessment of the budget devoted to diet	Computation of the indicators taking into account the place of purchase of main food categories and differentiating the food production systems (organic vs. conventional) and further allocations of edibility and cooking factors to obtain impacts at the consumer level
Percentage of the total budget allocated to food	Economic-related dimension	NutriNet-Santé socio-economic questionnaire and computed diet monetary costs	Assessment of the importance placed on diet in the total budget	Division of the diet monetary cost by the household income reported by the participants. Because incomes were declared in categories, the mean of each class was used, whereas arbitrary incomes were determined for extreme classes
Dietary pesticide exposure	Toxicology-related dimension	Chemisches und Veterinäruntersuchungamt (European reference laboratory for the development of methods for the analysis of residues on plant products) Stuttgart database (2012–2015)	Measure of the exposure from plant-derived products to 15 pesticides	Assessment of the plant-based exposure based on 180 plant ingredients, differentiating the food production systems (organic vs. conventional), and further allocations of edibility and cooking factors to obtain impacts at the consumer level

TABLE 2 Participant characteristics across quintiles, $n = 29,210$, NutriNet-Santé¹

	Quintiles of proportion of organic food consumption in the diet					P^2
	Q1 0.00 to <0.01	Q2 0.01 to <0.09	Q3 0.09 to <0.25	Q4 0.25 to <0.50	Q5 0.50 to ≤ 1.00	
Unweighted, n (%)	3723 (13)	5112 (17)	6519 (22)	6649 (23)	7207 (25)	
Weighted, n (%)	5838 (20)	5840 (20)	5731 (20)	5954 (20)	5847 (20)	
Proportion of organic food in the diet (organic ratio) ³	0.00 \pm 0.00	0.04 \pm 0.02	0.17 \pm 0.04	0.34 \pm 0.06	0.71 \pm 0.15	<0.0001
Age, y	47.54 \pm 19.61	47.50 \pm 17.42	49.06 \pm 14.72	48.30 \pm 15.71	48.35 \pm 15.27	0.0007
Women, %	45.11	50.35	55.63	55.37	55.34	<0.0001
Educational level, %	—	—	—	—	—	<0.0001
Less than high-school diploma	67.92	60.76	57.07	57.97	54.03	
High school diploma	16.47	17.69	14.75	13.84	15.07	
Postgraduate	15.61	21.55	28.18	28.19	30.91	
Occupational status, %	—	—	—	—	—	<0.0001
Unemployed	7.68	2.72	3.54	4.00	2.94	
Never employed	7.83	9.81	7.67	11.47	8.99	
Self-employed, farmer	5.69	4.46	2.31	3.05	6.71	
Employee, manual worker	38.22	37.2	29.03	26.02	25.51	
Intermediate professions	10.48	12.67	16.94	16.38	16.02	
Managerial staff, intellectual profession	5.53	6.81	11.38	10.52	11.28	
Retired	24.57	26.34	29.13	28.55	28.54	
Monthly income per household unit, %	—	—	—	—	—	<0.0001
Unwilling to answer	7.48	5.30	6.99	6.31	9.63	
<€1200	32.54	28.62	21.65	21.55	20.73	
€1200–1800	30.99	30.95	30.11	27.35	23.46	
€1800–2700	19.95	20.83	24.45	25.78	30.30	
>€2700	9.04	14.30	16.81	19.01	15.88	
Place of residence, %	—	—	—	—	—	<0.0001
Rural community	22.86	21.62	25.87	26.24	29.62	
Urban unit with a population <20,000 inhabitants	15.57	20.60	15.12	18.58	15.59	
Urban unit with a population between 20,000 and 200,000 inhabitants	15.35	15.01	18.40	16.77	13.28	
Urban unit with a population >200,000 inhabitants	46.21	42.77	40.61	38.40	41.50	
Smoking habits, %	—	—	—	—	—	<0.0001
Never smoker	45.66	48.34	45.53	48.11	50.16	
Former smoker	39.82	38.39	41.60	42.13	41.51	
Current smoker	14.52	13.27	12.86	9.75	8.33	
Physical activity, %	—	—	—	—	—	<0.0001
Missing data	20.50	18.65	14.34	12.03	8.86	
Low	24.62	25.09	21.05	21.79	13.22	
Moderate	27.43	26.33	34.01	31.43	31.53	
High	27.45	29.92	30.60	34.76	46.39	

¹All values presented are weighted data (unless otherwise specified). Values are means \pm SDs or %, as appropriate. Q, quintile.

² P values are based on linear contrast test for continuous variables or Mantel–Haenszel chi-square test for categorical variable. For occupational status and place of residence, p -values are based on chi-square test, because the variables were not ordinal.

³Determined by dividing the total organic food intake (g/d) by the total food intake without water (g/d).

patterns, assuming the same food prices in both quintiles (and then assuming that Q5 do not consume organic foods).

- (2) The “production system effect,” that is the diet monetary cost difference between Q1 and Q5 owing to the difference in food prices, assuming that Q1 consume the same proportion of organic foods as Q5.
- (3) The “cross-effect” of the 2 previous ones, which is the residual variation in diet monetary costs between Q1 and

Q5, associated with the simultaneous variation of dietary patterns and product prices.

Similar breakdowns were carried out for environmental and toxicological indicators. The analysis was applied to the 16 food groups. To take into account the intraquintile variability, upper and lower CIs of the variables were estimated by bootstrapping using 1000 replications (**Supplemental Material 5**).

TABLE 3 Food group intakes across quintiles, $n = 29,210$, NutriNet-Santé¹

	Quintiles of proportion of organic food consumption in the diet					P^2
	Q1 0.00 to <0.01	Q2 0.01 to <0.09	Q3 0.09 to <0.25	Q4 0.25 to <0.50	Q5 0.50 to ≤1.00	
Total weight, g/d	3305 ± 1574	3406 ± 1320	3460 ± 107	3536 ± 1063	3498 ± 910	0.0012
Food-group intakes, g/d						
Fruits and vegetables ± including juices and soups	586.69 ± 513.89	651.71 ± 551.92	636.78 ± 357.51	728.88 ± 379.50	893.55 ± 476.37	<0.0001
Seafood	31.62 ± 54.93	43.85 ± 47.36	43.49 ± 39.43	46.87 ± 39.56	36.93 ± 36.63	<0.0001
Meat, poultry, and processed meat	157.59 ± 138.42	140.85 ± 96.68	141.87 ± 85.71	122.07 ± 88.34	85.41 ± 76.53	<0.0001
Of which ruminant meat	53.11 ± 63.84	42.21 ± 39.95	43.81 ± 34.18	36.02 ± 39.09	25.77 ± 31.84	<0.0001
Eggs	10.32 ± 19.02	12.02 ± 12.28	11.28 ± 10.34	17.81 ± 35.84	11.30 ± 11.05	<0.0001
Dairy products	288.65 ± 276.33	299.61 ± 237.82	286.61 ± 204.02	287.74 ± 226.06	178.45 ± 167.81	<0.0001
Starchy foods	203.23 ± 154.42	224.88 ± 183.52	205.00 ± 116.81	195.56 ± 116.41	196.85 ± 126.80	<0.0001
Whole-grain products	24.65 ± 59.44	38.91 ± 58.41	41.04 ± 53.76	63.69 ± 99.00	99.05 ± 92.35	<0.0001
Oil	13.12 ± 18.00	17.55 ± 20.81	17.64 ± 14.29	20.24 ± 15.39	21.93 ± 14.81	<0.0001
Butter and margarine	7.35 ± 9.24	6.75 ± 7.41	6.76 ± 6.89	6.58 ± 6.75	5.11 ± 5.68	<0.0001
Sweetened foods	84.03 ± 98.32	77.05 ± 59.67	81.12 ± 58.69	71.33 ± 51.42	65.92 ± 46.83	<0.0001
Fast food	46.68 ± 73.16	43.22 ± 42.10	38.84 ± 33.90	76.34 ± 292.84	33.02 ± 27.29	0.35
Extra food ± including snacks, chips, salted biscuits, dressing, and sauces	18.02 ± 34.33	16.62 ± 18.08	17.54 ± 14.67	16.01 ± 13.49	21.78 ± 21.80	<0.0001
Dairy and meat substitutes ± including soya-based products	3.13 ± 31.60	10.16 ± 41.05	17.88 ± 70.20	47.75 ± 123.39	96.61 ± 168.98	<0.0001
Nonalcoholic beverages	1729.93 ± 1220.5	1741.09 ± 951.09	1807.54 ± 801.39	1753.76 ± 815.04	1666.18 ± 651.44	0.0004
Alcoholic beverages	104.02 ± 264.41	91.44 ± 153.74	111.87 ± 154.79	94.37 ± 124.38	87.72 ± 111.68	<0.0001
Other fats ± including mayonnaise, fresh cream, vegetable fresh cream	2.96 ± 5.61	3.38 ± 4.94	3.86 ± 6.38	3.35 ± 5.65	3.38 ± 4.47	0.0001

¹All values are means ± SDs and are presented as weighted data. Q, quintile.

² P values are based on linear contrast tests.

TABLE 4 Nutrition-related indicators across quintiles, $n = 29,210$, NutriNet-Santé¹

	Quintiles of proportion of organic food consumption in the diet										P^2
	Q1		Q2		Q3		Q4		Q5		
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	
	0.00 to <0.01	0.01 to <0.09	0.09 to <0.25	0.25 to <0.50	0.50 to ≤1.00						
Total energy intake, kcal/d											
Model 1 ³	2059	2041, 2077	2147	2129, 2165	2108	2089, 2126	2171	2153, 2189	2115	2097, 2133	<0.0001
Model 2 ⁴	2040	2022, 2058	2143	2125, 2161	2118	2100, 2136	2181	2163, 2199	2125	2107, 2143	<0.0001
Total fat, %											
Model 1 ³	40.11	39.92, 40.30	39.96	39.77, 40.14	40.95	40.76, 41.14	40.85	40.67, 41.04	40.83	40.65, 41.02	<0.0001
Model 2 ⁴	40.37	40.18, 40.55	40.20	40.01, 40.39	41.12	40.93, 41.31	41.06	40.87, 41.24	41.03	40.85, 41.22	<0.0001
Saturated fatty acids, %											
Model 1 ³	16.01	15.91, 16.11	15.31	15.22, 15.41	15.53	15.44, 15.63	14.96	14.86, 15.05	13.20	13.10, 13.30	<0.0001
Model 2 ⁴	15.98	15.89, 16.08	15.32	15.22, 15.42	15.57	15.47, 15.66	14.99	14.89, 15.09	13.23	13.14, 13.33	<0.0001
Monounsaturated fatty acids, %											
Model 1 ³	15.31	15.20, 15.41	15.40	15.30, 15.51	16.00	15.89, 16.10	16.09	15.99, 16.20	16.65	16.54, 16.75	<0.0001
Model 2 ⁴	15.48	15.37, 15.58	15.55	15.45, 15.66	16.09	15.99, 16.20	16.21	16.10, 16.31	16.76	16.65, 16.86	<0.0001
Polyunsaturated fatty acids, %											
Model 1 ³	5.78	5.72, 5.84	6.25	6.19, 6.31	6.37	6.31, 6.43	6.70	6.64, 6.76	7.95	7.89, 8.02	<0.0001
Model 2 ⁴	5.88	5.81, 5.94	6.32	6.26, 6.39	6.40	6.34, 6.46	6.74	6.68, 6.80	7.99	7.93, 8.06	<0.0001
Carbohydrates, %											
Model 1 ³	39.85	39.65, 40.05	40.32	40.11, 40.52	39.34	39.13, 39.54	39.91	39.71, 40.11	41.84	41.63, 42.04	<0.0001
Model 2 ⁴	39.52	39.31, 39.73	39.97	39.77, 40.18	39.07	38.87, 39.28	39.60	39.40, 39.80	41.53	41.33, 41.74	<0.0001
Added sugars, %											
Model 1 ³	6.33	6.24, 6.41	5.87	5.79, 5.96	5.81	5.72, 5.89	5.25	5.17, 5.34	4.81	4.73, 4.90	<0.0001
Model 2 ⁴	6.11	6.02, 6.19	5.66	5.57, 5.75	5.66	5.57, 5.75	5.08	4.99, 5.16	4.64	4.56, 4.73	<0.0001
Protein, %											
Model 1 ³	19.69	19.60, 19.79	19.37	19.27, 19.46	19.35	19.25, 19.44	18.87	18.77, 18.96	16.97	16.87, 17.06	<0.0001
Model 2 ⁴	19.76	19.66, 19.85	19.46	19.36, 19.55	19.44	19.34, 19.53	18.97	18.87, 19.06	17.07	16.97, 17.16	<0.0001

(Continued)

TABLE 4 (Continued)

	Quintiles of proportion of organic food consumption in the diet										P ²
	Q1		Q2		Q3		Q4		Q5		
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	
	0.00 to <0.01		0.01 to <0.09		0.09 to <0.25		0.25 to <0.50		0.50 to ≤1.00		
Plant/animal protein ratio											
Model 1 ³	0.46	-5.92, 6.85	0.45	-5.93, 6.84	0.60	-5.84, 7.05	3.61	-2.71, 9.93	14.29	7.91, 20.67	0.0022
Model 2 ⁵	-0.67	-7.10, 5.86	-0.62	-7.15, 5.80	-0.12	-6.62, 6.37	2.66	-3.73, 9.06	13.42	6.97, 19.87	0.0018
Fiber, g/d											
Model 1 ³	19.07	18.79, 19.36	21.68	21.39, 21.96	21.50	21.21, 21.79	24.24	23.96, 24.52	30.91	30.63, 31.20	<0.0001
Model 2 ⁵	20.27	20.04, 20.50	21.83	21.60, 22.06	21.80	21.57, 22.03	23.95	23.73, 24.18	31.19	30.97, 31.42	<0.0001
Vitamin C, mg/d											
Model 1 ³	133.3	130.8, 135.8	140.1	137.6, 142.6	140.8	138.3, 143.4	160.0	157.5, 162.4	184.2	181.7, 186.7	<0.0001
Model 2 ⁵	140.8	138.6, 143.1	140.9	138.7, 143.2	142.0	139.7, 144.3	157.7	155.4, 159.9	185.2	182.9, 187.5	<0.0001
Vitamin E, mg/d											
Model 1 ³	12.60	12.42, 12.78	14.34	14.15, 14.52	13.87	13.69, 14.06	14.98	14.80, 15.16	17.22	17.04, 17.41	<0.0001
Model 2 ⁵	13.47	13.33, 13.61	14.44	14.30, 14.58	14.05	13.91, 14.19	14.74	14.61, 14.88	17.39	17.25, 17.53	<0.0001
Heme iron, mg/d											
Model 1 ³	1.86	1.82, 1.90	1.60	1.56, 1.63	1.59	1.56, 1.63	1.44	1.41, 1.48	0.99	0.95, 1.03	<0.0001
Model 2 ⁵	1.91	1.88, 1.94	1.59	1.55, 1.62	1.62	1.59, 1.66	1.42	1.39, 1.46	1.02	0.98, 1.05	<0.0001
Calcium, mg/d											
Model 1 ³	1128	1116, 1140	1199	1187, 1211	1163	1151, 1175	1178	1166, 1190	1070	1058, 1082	<0.0001
Model 2 ⁵	1175	1167, 1184	1197	1188, 1206	1172	1163, 1181	1158	1149, 1167	1077	1069, 1086	<0.0001
Dietary scores											
Modified Programme National Nutrition Santé Guideline Score, /13.5											
Model 1 ³	7.64	7.60, 7.69	7.97	7.93, 8.02	8.09	8.05, 8.14	8.31	8.26, 8.35	8.59	8.55, 8.64	<0.0001
Model 2 ⁶	7.80	7.76, 7.84	8.25	8.21, 8.29	8.31	8.27, 8.35	8.60	8.56, 8.64	8.83	8.79, 8.87	<0.0001
Probability of Adequate Nutrient Intake Diet, /100											
Model 1 ³	62.03	61.86, 62.21	64.12	63.95, 64.29	64.55	64.37, 64.72	66.21	66.04, 66.38	68.73	68.55, 68.90	<0.0001
Model 2 ⁶	62.52	62.35, 62.69	64.73	64.56, 64.90	64.95	64.78, 65.12	66.77	66.61, 66.94	69.18	69.01, 69.35	<0.0001
BMI, kg/m ²											
Model 1 ³	26.93	26.77, 27.08	25.60	25.45, 25.75	24.85	24.70, 25.00	24.34	24.19, 24.48	23.04	22.89, 23.19	<0.0001
Model 2 ⁶	27.26	27.11, 27.41	25.93	25.78, 26.08	25.13	24.98, 25.28	24.63	24.48, 24.78	23.36	23.21, 23.51	<0.0001

¹All values presented are weighted data. Q, quintile.

²P values are based on linear contrast tests (corrected for multiple comparisons using a Bonferroni procedure).

³Model 1: unadjusted.

⁴Model 2: adjusted for age and gender. Macronutrients are expressed as a percentage of alcohol-free energy intake.

⁵Model 2: adjusted for age, gender, and daily energy intake using the residual method.

⁶Model 2: adjusted for age, gender, and daily energy intake.

TABLE 5 Environment-related indicators across quintiles, $n = 29,210$, NutriNet-Santé¹

	Quintiles of proportion of organic food consumption in the diet									
	Q1		Q2		Q3		Q4		Q5	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
	0.00 to <0.01		0.01 to <0.09		0.09 to <0.25		0.25 to <0.50		0.50 to ≤1.00	
Greenhouse gas emissions, kg CO ₂ -eq/d	5.20	5.13, 5.26	4.78	4.71, 4.85	4.67	4.60, 4.74	4.36	4.28, 4.42	3.38	3.30, 3.44
Model 1 ³	5.07	5.01, 5.12	4.48	4.42, 4.53	4.48	4.43, 4.54	4.02	3.97, 4.08	3.17	3.12, 3.23
Cumulative energy demand, MJ/d	19.98	19.76, 20.19	19.60	19.39, 19.81	19.16	18.95, 19.38	18.82	18.61, 19.03	15.42	15.21, 15.63
Model 1 ³	19.72	19.58, 19.85	18.59	18.45, 18.73	18.45	18.31, 18.58	17.58	17.44, 17.72	14.67	14.54, 14.81
Land occupation, m ² /d	12.69	12.50, 12.88	11.75	11.55, 11.94	11.87	11.68, 12.07	11.54	11.35, 11.73	10.02	9.83, 10.21
Model 1 ³	12.35	12.19, 12.51	10.99	10.83, 11.15	11.40	11.24, 11.56	10.72	10.56, 10.87	9.52	9.36, 9.68
Model 2 ⁴										

¹All values presented are weighted data. Q, quintile.²P values are based on linear contrast tests (corrected for multiple comparisons using a Bonferroni procedure).³Model 1: unadjusted.⁴Model 2: adjusted for age, gender, and daily energy intake.

Results

Sample characteristics

The sociodemographic characteristics of the weighted study sample are presented in **Table 2**. Individuals in the lowest quintile of proportion of organic food consumption in the diet (Q1) consumed no organic food, whereas organic food made up, on average, 71% of the diet of individuals in the top quintile (Q5). Intake of plant-based products increased along with the proportion of organic food in the diet (+52.30%), whereas intake of meat-based products (−45.80%) and sweetened foods decreased across quintiles (−21.55%) (**Table 3**).

Diet sustainability indicators across organic-food-consumption quintiles

Compared with the participants in Q1, those in Q5 showed lower contributions of saturated fatty acids, added sugars, and proteins in their energy intake, as well as a higher contribution of poly-unsaturated fatty acids (**Table 4**). The plant/animal protein consumption ratio was considerably higher in Q5 than in other quintiles. Participants in Q5 had a higher intake of fiber and vitamins C and E than other quintiles. Overall, a higher organic food consumption was associated with a better nutritional quality of the diet (higher scores) and lower BMIs. Nonadjusted and adjusted models yielded similar trends.

The associations between quintiles of proportion of organic food consumption in the diet and environmental impacts are presented in **Table 5**. The GHGEs, CED, and land occupation decreased strongly across quintiles, by around 30%, 20%, and 20%, respectively. In unadjusted models, the differences between Q5 compared with Q1 were 1.82 kg CO₂-eq, 4.56 MJ, and 2.67 m², respectively. Similar linear relations were obtained after multivariable adjustment.

Table 6 shows the results of the crude and adjusted means for diet monetary costs by quintiles of proportion of organic food consumption in the diet. A higher proportion of organic food in the diet was related to higher diet monetary costs (€8.97/d compared with €7.11/d in Q5 and Q1, respectively, in the adjusted model). The percentage of the total income devoted to food was the highest in Q5.

Table 7 lists the EDI levels for 15 pesticides using the lower-bound scenario. In the adjusted models, the lowest means of EDIs were observed in Q5 for most pesticides, except for pyrethrins and spinosad.

Breakdown of the effects

Figure 1 provides a breakdown of the variation for environmental and economic indicators between Q1 and Q5. Regarding GHGEs, the 32.51% reduction between Q1 and Q5 was only attributed to the “dietary pattern effect.” Concerning CED, the 20.55% reduction was mainly due to the “dietary pattern effect” and, to a lesser extent, the “production system effect” (4%). As regards land occupation, the “production system effect” induced a 18.06% increase, and the “dietary pattern effect” a 30.17% decrease. The total diet monetary cost in Q5 was 26.08% higher than in Q1. The “production system effect” induced a 24.78% increase in the total diet monetary cost, whereas the “dietary

TABLE 6 Economic-related indicators across quintiles, $n = 29,210$, NutriNet-Santé¹

	Quintiles of proportion of organic food consumption in the diet										P^2
	Q1		Q2		Q3		Q4		Q5		
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	
Total diet monetary cost, €/d											
Model 1 ³	7.00	6.92, 7.08	7.32	7.25, 7.40	7.60	7.53, 7.68	8.00	7.92, 8.07	8.79	8.71, 8.86	<0.0001
Model 2 ⁴	7.11	7.03, 7.18	7.48	7.41, 7.55	7.77	7.698, 7.85	8.19	8.11, 8.26	8.97	8.90, 9.05	<0.0001
Cost of the diet dedicated to conventional foods, €/d											
Model 1 ³	6.99	6.93, 7.05	6.87	6.81, 6.93	6.22	6.16, 6.28	5.13	5.07, 5.18	2.71	2.65, 2.77	<0.0001
Model 2 ⁴	7.09	7.03, 7.15	7.02	6.96, 7.07	6.36	6.30, 6.42	5.29	5.23, 5.34	2.87	2.81, 2.92	<0.0001
Cost of the diet dedicated to organic foods, €/d											
Model 1 ³	0.02	-0.03, 0.06	0.45	0.40, 0.49	1.38	1.34, 1.43	2.87	2.83, 2.91	6.08	6.03, 6.12	<0.0001
Model 2 ⁴	0.02	-0.03, 0.06	0.47	0.42, 0.51	1.41	1.368, 1.46	2.90	2.86, 2.94	6.11	6.06, 6.15	<0.0001
Percentage of the monthly income devoted to food, % ⁵											
Model 1 ³	19.39	18.95, 19.84	19.88	19.43, 20.32	17.57	17.12, 18.02	17.94	17.50, 18.38	20.83	20.37, 21.28	0.021
Model 2 ⁴	18.77	18.32, 19.22	19.21	18.77, 19.66	17.12	16.67, 17.57	17.40	16.96, 17.84	20.35	19.90, 20.81	<0.0001

¹All values presented are weighted data. Q, quintile.

² P values are based on linear contrast tests (corrected for multiple comparisons using a Bonferroni procedure).

³Model 1: unadjusted.

⁴Model 2: adjusted for age, gender, and daily energy intake.

⁵Question pertaining to income was optional, so the sample size was 27,444.

TABLE 7 Dietary (plant food) exposure to selected pesticides across quintiles, lower-bound scenario, $n = 29,210$, NutriNet-Santé¹

Pesticides ($\mu\text{g}/\text{kg}$ bw/d)	Quintiles of proportion of organic food consumption in the diet												P^2			
	Q1			Q2			Q3			Q4				Q5		
	Mean	95% CI	0.00 to <0.01	Mean	95% CI	0.01 to <0.09	Mean	95% CI	0.09 to <0.25	Mean	95% CI	0.25 to <0.50		Mean	95% CI	0.50 to ≤ 1.00
Acetamiprid	0.0385	0.0372, 0.0398	0.0432	0.0419, 0.0445	0.0445	0.0432, 0.0458	0.0423	0.0410, 0.0436	0.0190	0.0177, 0.0203	<0.0001					
Model 1 ³	0.0456	0.0444, 0.0468	0.0477	0.0465, 0.0490	0.0479	0.0467, 0.0492	0.0432	0.0419, 0.0444	0.0148	0.0136, 0.0161	<0.0001					
Model 2 ⁴	0.036	0.0350, 0.0370	0.0409	0.0399, 0.0419	0.0426	0.0416, 0.0436	0.0418	0.0408, 0.0428	0.0249	0.0239, 0.0259	<0.0001					
Carbendazim	0.042	0.0411, 0.0430	0.0446	0.0437, 0.0456	0.0454	0.0444, 0.0463	0.0423	0.0414, 0.0432	0.0210	0.0201, 0.0220	<0.0001					
Model 1 ³	0.0999	0.0972, 0.1027	0.1038	0.1011, 0.1066	0.0773	0.0745, 0.0801	0.0789	0.0762, 0.0816	0.0293	0.0265, 0.0320	<0.0001					
Model 2 ⁴	0.1005	0.0977, 0.1033	0.1045	0.1017, 0.1073	0.0795	0.0767, 0.0823	0.0791	0.0764, 0.0818	0.0262	0.0234, 0.0290	<0.0001					
Chlorpropham	0.0620	0.0606, 0.0634	0.0663	0.0649, 0.0677	0.0616	0.0602, 0.0630	0.0598	0.0584, 0.0612	0.0311	0.0297, 0.0325	<0.0001					
Chlorpyrifos	0.0710	0.0697, 0.0723	0.0722	0.0709, 0.0735	0.0661	0.0648, 0.0674	0.0613	0.0600, 0.0626	0.0264	0.0251, 0.0277	<0.0001					
Model 1 ³	0.0510	0.0491, 0.0529	0.0583	0.0564, 0.0601	0.0629	0.0611, 0.0648	0.0630	0.0612, 0.0649	0.0376	0.0358, 0.0395	<0.0001					
Model 2 ⁴	0.0608	0.0591, 0.0626	0.0643	0.0625, 0.0660	0.0676	0.0658, 0.0693	0.0638	0.0621, 0.0656	0.0310	0.0292, 0.0328	<0.0001					
Cypermethrin	0.0159	0.0155, 0.0162	0.0179	0.0175, 0.0182	0.0157	0.0153, 0.0161	0.0153	0.0150, 0.0157	0.0080	0.0077, 0.0084	<0.0001					
Model 1 ³	0.0181	0.0177, 0.0184	0.0194	0.0191, 0.0198	0.0169	0.0166, 0.0173	0.0159	0.0156, 0.0163	0.0073	0.0070, 0.0077	<0.0001					
Model 2 ⁴	0.0027	0.0026, 0.0028	0.0028	0.0028, 0.0029	0.0028	0.0027, 0.0029	0.0030	0.0030, 0.0031	0.0018	0.0018, 0.0019	<0.0001					
Dimethoate	0.0032	0.0031, 0.0033	0.0032	0.0031, 0.0032	0.0031	0.0030, 0.0032	0.0031	0.0031, 0.0032	0.0016	0.0016, 0.0017	<0.0001					
Imazalil	0.8763	0.8536, 0.8990	0.8512	0.8285, 0.8739	0.7398	0.7169, 0.7627	0.7460	0.7236, 0.7685	0.3501	0.3274, 0.3727	<0.0001					
Model 1 ³	0.9696	0.9470, 0.9922	0.9165	0.8941, 0.9390	0.7912	0.7687, 0.8137	0.7701	0.7480, 0.7921	0.3158	0.2933, 0.3384	<0.0001					
Model 2 ⁴	0.0700	0.0682, 0.0718	0.0701	0.0683, 0.0719	0.0729	0.0711, 0.0748	0.0782	0.0764, 0.0800	0.0645	0.0627, 0.0663	0.3242					
Imidacloprid	0.0738	0.0720, 0.0756	0.0713	0.0695, 0.0730	0.0741	0.0724, 0.0759	0.0760	0.0743, 0.0778	0.0567	0.0549, 0.0585	<0.0001					
Model 1 ³																
Model 2 ⁴																

(Continued)

TABLE 7 (Continued)

Pesticides ($\mu\text{g}/\text{kg}$ bw/d)	Quintiles of proportion of organic food consumption in the diet												P^2
	Q1		Q2		Q3		Q4		Q5		Mean	95% CI	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI			
	0.00 to <0.01	0.01 to <0.09	0.09 to <0.25	0.25 to <0.50	0.50 to ≤ 1.00								
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	
Lambda-cyhalothrin													
Model 1 ³	0.0100	0.0098, 0.0102	0.0113	0.0111, 0.0115	0.0096	0.0093, 0.0098	0.0085	0.0083, 0.0088	0.0049	0.0047, 0.0051	0.0049	0.0047, 0.0051	<0.0001
Model 2 ⁴	0.0116	0.0114, 0.0119	0.0125	0.0123, 0.0127	0.0104	0.0102, 0.0106	0.0091	0.0089, 0.0093	0.0047	0.0045, 0.0049	0.0047	0.0045, 0.0049	<0.0001
Methamidophos													
Model 1 ³	0.0004	0.0004, 0.0004	0.0004	0.0004, 0.0004	0.0003	0.0003, 0.0003	0.0003	0.0003, 0.0003	0.0001	0.0001, 0.0001	0.0001	0.0001, 0.0001	<0.0001
Model 2 ⁴	0.0004	0.0004, 0.0004	0.0003	0.0003, 0.0004	0.0003	0.0003, 0.0003	0.0003	0.0003, 0.0003	0.0001	0.0001, 0.0001	0.0001	0.0001, 0.0001	<0.0001
Profenofos													
Model 1 ³	0.0001	0.0000, 0.0001	0	0.0000, 0.0000	0	0.0000, 0.0000	0	0.0000, 0.0000	0	0.0000, 0.0000	0	0.0000, 0.0000	<0.0001
Model 2 ⁴	0.0001	0.0001, 0.0001	0	0.0000, 0.0001	0	0.0000, 0.0000	0	0.0000, 0.0000	0	0.0000, 0.0000	0	0.0000, 0.0000	<0.0001
Pyrethrins													
Model 1 ³	0.0023	0.0022, 0.0024	0.0029	0.0028, 0.0029	0.0023	0.0022, 0.0023	0.0022	0.0022, 0.0023	0.0028	0.0028, 0.0029	0.0028	0.0028, 0.0029	0.0001
Model 2 ⁴	0.0022	0.0021, 0.0022	0.0027	0.0026, 0.0027	0.0021	0.0021, 0.0022	0.0021	0.0020, 0.0021	0.0025	0.0025, 0.0026	0.0025	0.0025, 0.0026	0.2239
Spinosad													
Model 1 ³	0.0350	0.0314, 0.0387	0.0525	0.0488, 0.0561	0.0991	0.0954, 0.1028	0.1391	0.1355, 0.1427	0.2137	0.2100, 0.2173	0.2137	0.2100, 0.2173	<0.0001
Model 2 ⁴	0.0533	0.0497, 0.0568	0.0654	0.0619, 0.0690	0.1090	0.1054, 0.1125	0.1443	0.1408, 0.1478	0.2084	0.2048, 0.2120	0.2084	0.2048, 0.2120	<0.0001
Tebuconazole													
Model 1 ³	0.0357	0.0346, 0.0367	0.0395	0.0384, 0.0406	0.0320	0.0309, 0.0331	0.0284	0.0274, 0.0295	0.0167	0.0156, 0.0178	0.0167	0.0156, 0.0178	<0.0001
Model 2 ⁴	0.0420	0.0410, 0.0430	0.0444	0.0433, 0.0454	0.0356	0.0345, 0.0366	0.0309	0.0299, 0.0319	0.0165	0.0155, 0.0175	0.0165	0.0155, 0.0175	<0.0001

¹All values presented are weighted data. bw, body weight; Q, quintile.

²P values are based on linear contrast tests (corrected for multiple comparisons using a Bonferroni procedure).

³Model 1: unadjusted.

⁴Model 2: adjusted for age, gender, energy intake, and percentage of diet covered by the data (coverage of diet).

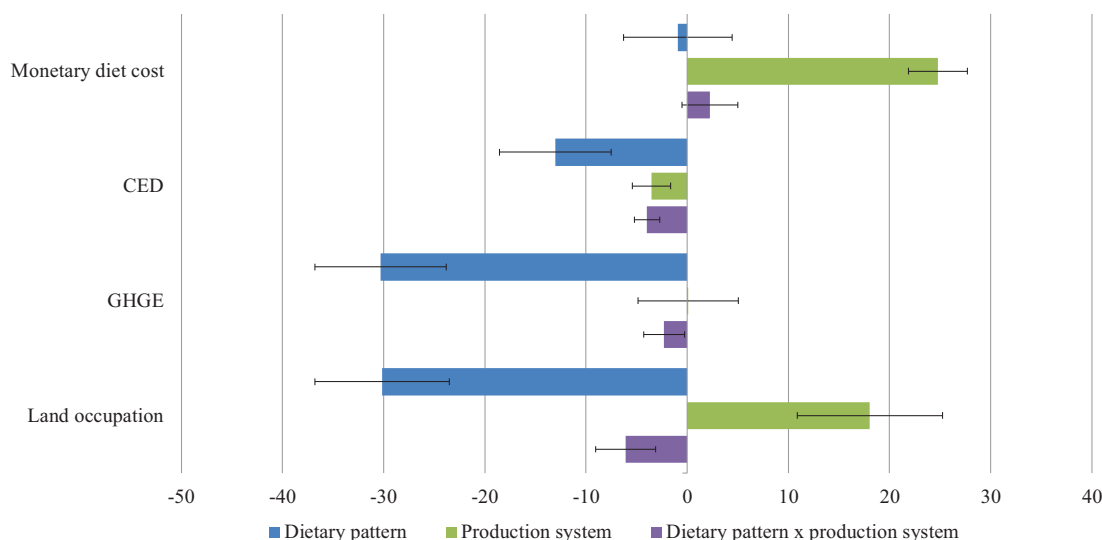


FIGURE 1 Breakdown of the variation in economic and environmental indicators between Q1 and Q5 (%), $n = 29,210$, NutriNet-Santé. Values are means 95% CI. All values presented are weighted data. Upper and lower CIs of the variables were estimated by bootstrapping using 1000 replications. Example: Comparing Q5 with Q1, an overall decrease in CED of 20.55% was observed. About 13% was due to a “dietary pattern effect,” whereas 3.5% was due to the “production system effect.” CED, cumulative energy demand; GHGE, greenhouse-gas emissions; Q, quintile.

pattern effect” induced a reduction of 0.92%, and the “cross effect” a 2.22% increase. Regarding pesticide exposure (Figure 2), the “production system effect” induced marked reductions (from -73.81% [metamidophos] to -15.30% [imidacloprid]) for all pesticides, except spinosad used mainly in organic agriculture, whereas the “dietary pattern effect” induced increases, in most cases (except for chlorpropham), when comparing Q5 with Q1 (from -3.05 to 55.44%).

Discussion

The present study evaluated diet sustainability across different levels of organic food consumption in adults through a broad diversity of indicators using observational data from the NutriNet-Santé cohort. Using a multidisciplinary approach, our analysis provides an original assessment of the sustainability, at the individual level, of self-selected dietary patterns by using quantitative data and simultaneously considering nutritional, environmental, toxicological, and economic indicators. Furthermore, the large size of our sample allowed us to cover a broad range of eating habits, and accurate and validated dietary data were available. To our knowledge, this is the first study comparing various indicators between organic and conventional consumers using a large and precise environmental data set based on updated real observations (38), and the first work integrating dietary exposure to pesticides in its definition of diet sustainability while differentiating the production system.

Consistent with the available literature (27–30), we showed that consumers characterized by high organic food consumption showed a higher consumption of plant foods, higher intakes of most vitamins, minerals, and fibers, better nutritional quality scores (27–30), and a lower BMI (27, 44) than the rest of the participants, reflecting their more healthful dietary patterns and favorable lifestyles. They also had lower environmental impacts and lower pesticide exposure levels, except for pesticides also

used in organic farming (spinosad and pyrethrins), but higher diet monetary costs than their counterparts.

Overall, the differences observed between low and high organic food consumers were mostly related to diet composition rather than the production system (i.e., organic or conventional), except for dietary pesticide exposure, diet monetary cost, and, to a lesser extent, CED.

Regarding environmental indicators, our results are in line with those of previous studies that showed that reductions in meat consumption are a determining factor for reducing diet-related environmental impacts (3, 13, 25). However, very few studies have dealt with the effects of organic compared with conventional consumption.

To our knowledge, only 1 recent study has compared conventional and organic food consumers in Germany (45). This study found that the average organic diet used 40% more land than the average conventional diet, and the carbon footprints of both diets were essentially equal. One explanation for the discrepancy with our present results may be that, in the German study, the assessment of organic food consumption was only based on a simple question pertaining to the overall frequency of organic food consumption: as a result, the entire diet was considered to be organic, likely leading to a large overestimation of the organic food impact and omitting the diversity of eating behaviors.

Using production data, rather than consumption data, a recent meta-analysis (13), in accordance with our findings, showed that organic systems emit comparable GHGEs per amount of food, require more land owing to lower yields, and require less energy than conventional systems, leading the authors to conclude that dietary shifts toward low-impact foods and increases in agricultural input use efficiency would offer larger environmental benefits than switching to alternative systems such as organic agriculture. Another recent study on food systems (46) using a modeling approach showed that a 100% conversion to

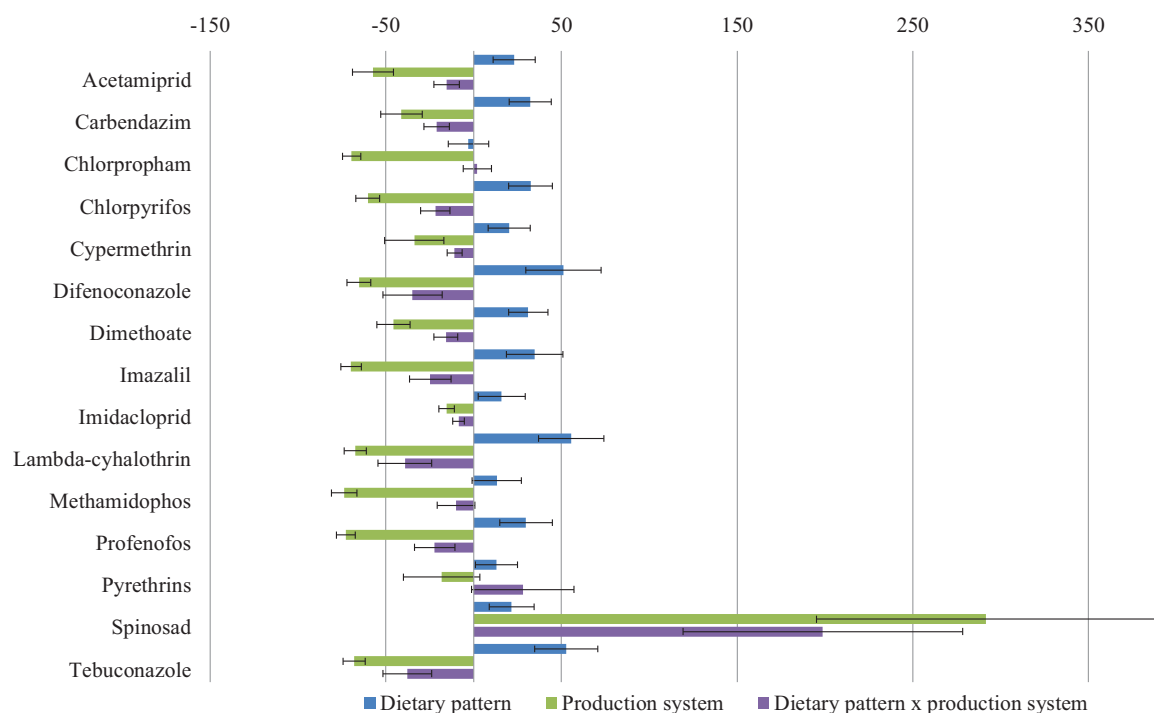


FIGURE 2 Breakdown of the variation in pesticide exposure between Q1 and Q5, lower-bound scenario (%), $n = 29,210$, NutriNet-Santé. Values are means 95% CI. All values presented are weighted data. Upper and lower CIs of the variables were estimated by bootstrapping using 1000 replications.

organic agriculture would require more land than conventional agriculture but would reduce N surplus and pesticide use.

Regarding health dimensions, in addition to the better diet quality and lower BMI of organic consumers, our study provided original results on the comparison of dietary pesticide exposure between individuals with various levels organic food consumption. It clearly appears that increasing plant-based foods results in an increase in pesticide exposure. Overall, under the lower-bound scenario that tends to underestimate the exposure, higher organic food consumption was, for almost all chemical pesticides (but not for pyrethrins and spinosad), linked to lower dietary exposure. This corresponds to the much lower pesticide contamination levels found in organic foods than in conventional foods (9). This also fits with the reduction in urinary organophosphate pesticide metabolites systematically observed during crossover intervention studies comparing conventional and organic diets (47).

Regarding the economic dimension, in line with previous research conducted in a French sample on the basis of purchase data (24), we found that a higher organic food consumption was associated with higher diet monetary costs for consumers. However, in this previous study, the “dietary pattern effect” was stronger than in ours, leading to a stronger decrease in the diet monetary cost when consumers move from animal- to plant-based diets with conventional products.

Some limitations should be considered. First, the NutriNet-Santé cohort is composed of volunteers, necessarily interested in food issues. Although potential selection bias was addressed by using a weighting procedure, this may have been insufficient to fully overcome the bias selection. Another possible consequence

is that our analysis may underestimate the “dietary pattern effect.” In particular, the self-reported intake of fruit and vegetables was rather high compared with official national figures (48). In addition, the patterns found herein cannot be extrapolated to developing countries because the importance of environmental impacts varies considerably, depending on the transitional stage of the region.

Second, food-consumption data were self-reported. The use of a 5-point ordinal scale has probably led to an overestimation of the actual organic food consumption. However, data collection regarding overall food consumption was derived from a validated food-frequency questionnaire that had shown relative validity and reproducibility (32). Third, the production system was not taken into account when evaluating nutritional values of foods. This may have led to an underestimation of some nutrient intakes in the case of organic food consumers (9). Fourth, owing to a paucity of studies on postfarm impacts in both conventional and organic agriculture, the life cycle assessment analyses were limited to the prefarm and on-farm activities. Transportation, distribution of waste, and losses through the supply chain were not included in the evaluation of the environmental impacts. Fifth, data were lacking regarding some pesticides largely sprayed on conventional farm crops such as glyphosate or dithiocarbamates. We also did not consider some major mineral-based pesticides used for pest control in organic production because data were not available. This is an important limitation because, for example, copper or sulfate may represent a high toxicity. Furthermore, our pesticide data were based on German contaminations, which may differ from those in France; however, both countries comply with the same European organic farming standards (8). Finally,

as regards cost data, we reasoned on mean price values, which constitutes an approximation. It should also be noted that potential positive externalities of organic food systems (7) are not considered in the present work.

Conclusion

The present study, based on observed data, adds to our understanding of the relation between various components of diet sustainability and organic food consumption. We showed that organic food consumption was associated with overall more sustainable diets because it often occurs in tandem with healthier dietary patterns. High-organic-food consumers were characterized by overall healthy and environmentally friendly food profiles, largely due to their plant-based dietary patterns, whereas their potential lowered pesticide exposure was probably due to the farming system. However, the monetary cost of their diets was higher.

Important indicators should be considered in further research, such as well-being and disease risk, biodiversity and ecotoxicity impacts, nitrate and pesticide leaching, soil quality, or water use, for which differences have been found between the 2 production systems. Further studies should integrate environmental, health, and socially related components in the definition of diet sustainability.

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References

- Burlingame B, Dernini S. Sustainable diets and biodiversity, In International Scientific Symposium Biodiversity and Sustainable Diets United Against Hunger (2010: Rome, Italy), FAO Edition. [Internet]. Rome; 2012. Available from: www.fao.org/docrep/016/i3004e/i3004e.pdf
- Joint WHO-FAO Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases. Diet, nutrition, and the prevention of chronic diseases: Report of a WHO-FAO Expert Consultation. Geneva: World Health Organization; 2003.
- Tilman D, Clark M. Global diets link environmental sustainability and human health. *Nature* 2014;515:518–22.
- Garnett T. Food sustainability: Problems, perspectives and solutions. *Proc Nutr Soc* 2013;72:29–39.
- Collectif INSERM. Pesticides: Effets sur la santé, une expertise collective de l'Inserm [Internet]. Salle de presse | Inserm. 2013 [cited 2016 Aug 21]. Available from: <http://presse.inserm.fr/pesticides-effets-sur-la-sante-une-expertise-collective-de-linserm/8463/>.
- IFOAM EU Group. Organic in Europe: prospects and developments 2016. [Internet]. [cited 2017 Jul 3]. Available from: http://www.ifoam-eu.org/sites/default/files/ifoameu_organic_in_europe_2016.pdf.
- Reganold JP, Wachter JM. Organic agriculture in the twenty-first century. *Nat Plants* 2016;2:15221.
- Européenne, Communauté. "Règlement (CE) No 834/2007 du Conseil du 28 juin 2007 relatif à la production biologique et à l'étiquetage des produits biologiques et abrogeant le règlement (CEE) no 2092/91." *JO L* 189, 2007.
- Barański M, Średnicka-Tober D, Volakakis N, Seal C, Sanderson R, Stewart GB, Benbrook C, Biavati B, Markellou E, Giotis C, et al. Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: A systematic literature review and meta-analyses. *Br J Nutr* 2014;112:794–811.
- EFSA. The 2015 European Union Report on Pesticide Residues in Food. *EFSA Journal* 2017;11(3):3130.
- Średnicka-Tober D, Barański M, Seal CJ, Sanderson R, Benbrook C, Steinshamn H, Gromadzka-Ostrowska J, Rembiałkowska E, Skwarlo-Soñta K, Eyre M, et al. Higher PUFA and n-3 PUFA, conjugated linoleic acid, α -tocopherol and iron, but lower iodine and selenium concentrations in organic milk: A systematic literature review and meta- and redundancy analyses. *Br J Nutr* 2016;115:1043–60.
- Średnicka-Tober D, Barański M, Seal C, Sanderson R, Benbrook C, Steinshamn H, Gromadzka-Ostrowska J, Rembiałkowska E, Skwarlo-Soñta K, Eyre M, et al. Composition differences between organic and conventional meat: A systematic literature review and meta-analysis. *Br J Nutr* 2016;115:994–1011.
- Clark M, Tilman D. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environ Res Lett* 2017;12:064016.
- Lee KS, Choe YC, Park SH. Measuring the environmental effects of organic farming: A meta-analysis of structural variables in empirical research. *J Environ Manage* 2015;162:263–74.
- Lynch D. Environmental impacts of organic agriculture in temperate regions. [Internet]. *CAB Rev Perspect Agric Vet Sci Nutr Nat Resour* 2012 [cited 2015 Jan 7];7. Available from: <http://orprints.org/20725/>
- Lori M, Symmaczik S, Mäder P, De Deyn G, Gattiger A. Organic farming enhances soil microbial abundance and activity—A meta-analysis and meta-regression. *PLoS One* 2017;12:e0180442.
- Tuck SL, Winqvist C, Mota F, Ahnström J, Turnbull LA, Bengtsson J. Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. *J Appl Ecol* 2014;51:746–55.
- Gomiero T, Pimentel D, Paoletti MG. environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Crit Rev Plant Sci* 2011;30:95–124.
- Tuomisto HL, Hodge ID, Riordan P, Macdonald DW. Does organic farming reduce environmental impacts?—A meta-analysis of European research. *J Environ Manage* 2012;112:309–20.
- Mondelaers K, Aertsens J, Van Huylenbroeck G. A meta-analysis of the differences in environmental impacts between organic and conventional farming. *Br Food J* 2009;111:1098–119.
- Buratti C, Fantozzi F, Barbanera M, Lascaro E, Chiorri M, Cecchini L. Carbon footprint of conventional and organic beef production systems: An Italian case study. *Sci Total Environ* 2017;576:129–37.
- Meemken E-M, Qaim M. Organic agriculture, food security, and the environment. *Annu Rev Resour Econ* 2018;10(1):39–63.
- Meier S M, Stoessel F, Jungbluth N, Juraske R, Schader C, Stolze M. Environmental impacts of organic and conventional agricultural products – Are the differences captured by life cycle assessment? *Journal of Environmental Management*. 2015;193:208.
- Boizot-Szantai C, Hamza O, Soler L-G. Organic consumption and diet choice: An analysis based on food purchase data in France. [Internet]. *Appetite* 2017 [cited 2017 Jul 31]. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S0195666317305950>
- Perignon M, Vieux F, Soler L-G, Masset G, Darmon N. Improving diet sustainability through evolution of food choices: Review of epidemiological studies on the environmental impact of diets. *Nutr Rev* 2017;75:2–17.

26. Petersen SB, Rasmussen MA, Strøm M, Halldorsson TI, Olsen SF. Sociodemographic characteristics and food habits of organic consumers—a study from the Danish National Birth Cohort. *Public Health Nutr* 2013;16:1810–9.
27. Eisinger-Watzl M, Wittig F, Heuer T, Hoffmann I. Customers purchasing organic food—do they live healthier? Results of the German National Nutrition Survey II. *Eur J Nutr Food Saf* 2015;5:59–71.
28. Simões-Wüst AP, Moltó-Puigmarí C, van Dongen MC, Dagnelie PC, Thijs C. Organic food consumption during pregnancy is associated with different consumer profiles, food patterns and intake: The KOALA Birth Cohort Study. *Public Health Nutr* 2017;20(12):2134–44.
29. Kesse-Guyot E, Péneau S, Méjean C, Szabo de Edelenyi F, Galan P, Hercberg S, Lairon D. Profiles of organic food consumers in a large sample of French adults: Results from the Nutrinet-Santé Cohort Study. *PLoS One* 2013;8:e76998.
30. Baudry J, Allès B, Péneau S, Touvier M, Méjean C, Hercberg S, Galan P, Lairon D, Kesse-Guyot E. Dietary intakes and diet quality according to levels of organic food consumption by French adults: Cross-sectional findings from the NutriNet-Santé Cohort Study. *Public Health Nutr* 2017;20(4):638–48.
31. Hercberg S, Castetbon K, Czernichow S, Malon A, Mejean C, Kesse E, Touvier M, Galan P. The Nutrinet-Santé Study: A web-based prospective study on the relationship between nutrition and health and determinants of dietary patterns and nutritional status. *BMC Public Health* 2010;10:242.
32. Kesse-Guyot E, Castetbon K, Touvier M, Hercberg S, Galan P. Relative validity and reproducibility of a food frequency questionnaire designed for French adults. *Ann Nutr Metab* 2010;57:153–62.
33. Le Moullec N, Deheeger M, Preziosi P, Monteiro P, Valeix P, Rolland-Cachera M-F, Potier De Courcy G, Christides J-P, Cherouvrier F, Galan P, et al. Validation du manuel-photos utilisé pour l'enquête alimentaire de l'étude SU.VI.MAX. *Cah Nutr Diététique* 1996;31:158–64.
34. Etude Nutrinet-Santé. Table de composition des aliments de l'étude Nutrinet-Santé (Nutrinet-Santé Study Food Composition Database). Paris: Economica. 2013.
35. Estaquio C, Kesse-Guyot E, Deschamps V, Bertrais S, Dauchet L, Galan P, Hercberg S, Castetbon K. Adherence to the French Programme National Nutrition Santé Guideline Score is associated with better nutrient intake and nutritional status. *J Am Diet Assoc* 2009;109:1031–41.
36. Verger EO, Mariotti F, Holmes BA, Paineau D, Huneau J-F. Evaluation of a diet quality index based on the Probability of Adequate Nutrient Intake (PANDiet) using National French and US Dietary Surveys. *PLoS One* 2012;7:e42155.
37. Seconda L, Baudry J, Allès B, Boizot-Szantai C, Soler L-G, Galan P, Hercberg S, Langevin B, Lairon D, Pointereau P, et al. Comparing nutritional, economic, and environmental performances of diets according to their levels of greenhouse gas emissions. *Clim Change* 2018;148(1-2):155–72.
38. Pointereau P, Langevin B, Gimaret M, others. DIALECTE, a comprehensive and quick tool to assess the agro-environmental performance of farms. [Internet]. 10th European IFSA Symposium, July [Internet]. 2012 [cited 2017 Jun 27]. p. 1–4. Available from: http://ifsa.boku.ac.at/cms/fileadmin/Proceeding2012/IFSA2012_WS1.3_Pointereau.pdf.
39. Kantar Worldpanel. Consumer Panels [cited 2017 Jul 4]. [Internet]. Available from: <https://www.kantarworldpanel.com/global>
40. EFSA. The 2015 European Union Report on pesticide residues in food. *EFSA J* 2017;11(3):3130.
41. CVUA Stuttgart. UA-BW [Internet]. [cited 2017 Jul 4]. Available from: <http://www.cvuas.de/pub/default.asp?subid=1>.
42. Nougadère A, Reninger J-C, Volatier J-L, Leblanc J-C. Chronic dietary risk characterization for pesticide residues: A ranking and scoring method integrating agricultural uses and food contamination data. *Food Chem Toxicol* 2011;49:1484–510.
43. INSEE. French national census data. [Internet]. 2009. Available from: <http://www.insee.fr/fr/ppp/bases-de-donnees/recensement/populations-legales/default.asp?annee=2009>.
44. Kesse-Guyot E, Baudry J, Assmann KE, Galan P, Hercberg S, Lairon D. Prospective association between consumption frequency of organic food and body weight change, risk of overweight or obesity: Results from the NutriNet-Santé Study. *Br J Nutr* 2017;117:325–34.
45. Treu H, Nordborg M, Cederberg C, Heuer T, Claupein E, Hoffmann H, Berndes G. Carbon footprints and land use of conventional and organic diets in Germany. *J Clean Prod* 2017;161:127–42.
46. Muller A, Schader C, Scialabba NE-H, Brüggemann J, Isensee A, Erb K-H, Smith P, Klocke P, Leiber F, Stolze M, et al. Strategies for feeding the world more sustainably with organic agriculture. *Nat Commun* 2017;8:1290.
47. Oates L, Cohen M, Braun L, Schembri A, Taskova R. Reduction in urinary organophosphate pesticide metabolites in adults after a week-long organic diet. *Environ Res* 2014;132:105–11.
48. ANSES. Étude individuelle nationale des consommations alimentaires 3 (INCA 3). [Internet]. 2017. Available from: <https://www.anses.fr/fr/system/files/NUT2014SA0234Ra.pdf>.