ORIGINAL RESEARCH

CURRENT DEVELOPMENTS IN NUTRITION

Food Composition, Nutritional Value, and Toxicology

Some Differences in Nutritional Biomarkers are Detected Between Consumers and Nonconsumers of Organic Foods: Findings from the BioNutriNet Project

Julia Baudry,[1] Véronique Ducros,[2] Nathalie Druesne-Pecollo,[1] Pilar Galan,[1] Serge Hercberg,[1,3] Laurent Debrauwer,[4] Marie Josèphe Amiot,[5] Denis Lairon,[6] and Emmanuelle Kesse-Guyot[1]

[1]Nutritional Epidemiology Research team (EREN), Paris 13 University, Inserm (U1153), Inra (U1125), Sorbonne Paris City Epidemiology and Statistics Center, Cnam, COMUE Sorbonne-Paris- City, Bobigny, France; [2]Biochemistry department, Grenoble-Alpes Hospital, Grenoble cedex 9, France; [3]Public Health Department, Avicenne hospital, AP-HP, Bobigny, France; [4]Toxalim, Université de Toulouse University, INRA, ENVT, INP-Purpan, UPS, Toulouse, France; [5]MOISA, Université Montpellier University, CIRAD, CIHEAM-IAMM, INRA, Montpellier SupAgro, Montpellier, France; and [6]Aix Marseille University, INSERM, INRA, Marseille, France

Abstract

Background: Meta-analyses have compared the nutrient content of both organic and nonorganic foods. However, the impacts of such variations on human nutritional biomarkers still need to be assessed.

Objective: In a nested clinical study from the NutriNet-Santé study, we aimed to compare the nutritional status of "organic" and "nonorganic" food consumers matched on a propensity score.

Methods: Based on self-reported organic food consumption assessed through a food frequency questionnaire (FFQ), 150 low and 150 high organic food consumers were selected with <10% or >50% of organic food in their diet, respectively (expressed as the proportion of organic food in the whole diet in g/d). Participants were matched using a propensity score derived from socio-demographic, food, and health variables. Fasting plasma samples were analyzed using acknowledged laboratory methods for measurements of iron status, magnesium, copper, cadmium, carotenoids, vitamins A and E, and fatty acids.

Results: We found significant differences between low and high organic food consumers with similar dietary patterns, with respect to plasma concentrations of magnesium, fat-soluble micronutrients (α-carotene, β-carotene, lutein, and zeaxanthin), fatty acids (linoleic, palmitoleic, γ-linolenic, and docosapentanoeic acids), and some fatty acid desaturase indexes. No differences between the 2 groups were detected for plasma concentrations of iron, copper, cadmium, lycopene, β-cryptoxanthin, or vitamins A and E.

Conclusion: If confirmed by other studies, our data suggest that a high consumption of organic foods, compared with very low consumption, modulates to some extent, the nutritional status of individuals with similar dietary patterns. Further research including prospective cohort studies is needed to evaluate the clinical relevance of such differences. *Curr Dev Nutr* 2018;3:nzy090.

Keywords: epidemiological study, vitamins, minerals, carotenoids, fatty acids, organic food, biomarkers

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Supplemental Tables 1–3 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/cdn/.

Address correspondence to EK-G (e-mail: e.kesse@eren.smbh.univ-paris13.fr).

Abbreviations used: DBP: diastolic blood pressure, mPNNS-GS: modified Programme National Nutrition Santé-guidelines score, Org-FFQ: organic semi-quantitative food frequency questionnaire, SBP: systolic blood pressure

Introduction

Over the past few years, the organic food market (1) has shown considerable development, especially in Europe. This growth has been largely driven by consumer concerns for food safety, a healthy diet, and the environment (2, 3). Organic products are considered healthier than conventional (nonorganic) products by consumers mainly because of their absence of synthetic pesticide residues (4–9). This is supported by findings from human trials revealing that replacing conventional foods with organic foods leads to a drastic reduction in urinary pesticide residues

and metabolites in various population subgroups (10–13). Observational data from cohorts conducted in the United States (14) and France (15) also confirm differences in exposure based on urinary pesticide metabolites.

Different practices between the production systems (organic/conventional) may also lead to differences in the content of several bioactive compounds and nutrients in both animal and plant-based foods. These differences may be related to changes in feeding regime and lifespans for animals, and fertilization and weed/pest control for crops. These factors could modulate the concentrations of some nutrients and/or defense secondary metabolites (16).

According to previous meta-analyses, compared with conventional foods, organic foods overall contain better nutritional content, including higher concentrations of specific antioxidants in plant foods and more beneficial fatty acid profiles in dairy products and meats (17–19).

The authors observed a higher amount of some phenolic compounds, including flavonoids and phenolic acid (range +18–69%), as well as higher concentrations of some carotenoids (xanthophylls) and vitamin C, and lower protein concentrations in organic plant foods compared with conventional plant foods. Two reviews have also reported trends towards higher magnesium concentrations in organic plant foods (20, 21). Data concerning comparisons of copper concentrations in foods are scarce although a study conducted on vegetables reported a higher copper content in organic lettuce, a lower content in peppers, and comparable concentrations in tomatoes (22).

Organic dairies were also shown to have a higher content of α-tocopherol and iron but lower iodine and selenium concentrations compared with conventional dairies (17).

The content of minerals and heavy metals in organic and conventional meats have been evaluated but the disparities in data did not allow stating the differences between the 2 production methods in a definitive manner (19).

Regarding toxic heavy metals, the meta-analysis of Baranski et al. (18) reported that organic crops, especially cereals, contained significantly lower concentrations of cadmium (−48%) compared with conventional crops.

With regard to fatty acid content, a pioneer review (23) and previous meta-analyses of 170 studies (20, 22) showed a higher content of PUFAs, and more markedly of nutritionally desirable omega-3 fatty acids (+56%) in organic milk and dairies. Moreover, a meta-analysis based on 67 comparative studies (20) showed that organic meats had significantly higher concentrations of total PUFAs (+23%) and n–3 PUFAs (+47%) with significantly lower MUFAs and slightly, but significantly, lower concentrations of saturated myristic and palmitic acids (20, 22).

Clinical studies comparing the nutritional status of consumers of organic or conventional foods are scarce and are based on poor methodologies that include a low number of subjects and short test durations, which have led to inconclusive findings (24). In a crossover trial in patients, urinary excretion of quercetin and kaempferol (2 main dietary phenolic compounds) were significantly increased after introducing an organic diet (25).

In this context, the objective of the present observational study was to test for differences in nutritional biomarkers among adults with low and high self-reported organic food consumption. These biomarkers included plasma concentrations of vitamins A and E, carotenoids, minerals (iron, magnesium, and copper), and a heavy metal (cadmium), as well as fatty acid profiles. We hypothesized that reported differences in food nutrient (or compound) content observed between the 2 farming systems (organic and conventional) could lead to higher plasma concentrations of the above-mentioned nutrients, vitamins, and minerals, but also to lower plasma concentrations of cadmium in organic food consumers compared with their conventional counterparts, independently of diet composition. Therefore, we matched the 2 groups on numerous traits, including food group consumption, in order to isolate the specific effect of the production system, beyond the dietary pattern structure, on some selected nutritional status biomarkers.

Methods

Study population

The NutriNet-Santé study is a web-based observational prospective study conducted on a large sample of adult volunteers. The overall objective is to study the link between nutrition and health (26). Adults (aged ≥18 y) are recruited from the general population through multimedia campaigns. All questionnaires are completed online using a dedicated and secure web platform.

In addition, participants were also invited, on a voluntary basis, to join health centers for biological sampling and clinical examination (2011–2013). A total of ∼20,000 volunteers were included in this subsample. Electronic and paper written informed consents were signed by all subjects attending the visit.

The NutriNet-Santé study is conducted according to the Declaration of Helsinki guidelines and was approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB Inserm n°0000388FWA00005831) and the Commission Nationale de l'Informatique et des Libertés (CNIL n°908,450/n°909,216/n°1,460,707). Electronic informed consent is obtained from each participant. All procedures of the clinical study were approved by the Consultation Committee for the Protection of Participants in Biomedical Research (C09–42 on 5th May 2010). The NutriNet-Santé study is registered at clinicaltrials.gov as #NCT03335644.

Data collection

At baseline and annually thereafter, participants were asked to complete questionnaires providing socio-demographic (age, sex, educational level, employment status, place of residence) and lifestyle (smoking status, physical activity) information and health data (menopausal status for women, medical history, and medication).

During the clinical visits, clinical outcomes were measured (systolic and diastolic blood pressure (SBP/DBP), weight, and height) using standardized procedures (27).

Hypertension, hypercholesterolemia, hypertriglyceridemia, and type II diabetes status were defined using standardized cut-offs: high BP (SBP/DBP ≥ 140/90 mmHg), hypertriglyceridemia (≥150 mg/dL), low high density lipoprotein-cholesterolemia (<40 mg/dL for men or <50 mg/dL for women), and hyperglycemia (fasting blood glucose <1.01 g/L).

Assessment of total and organic food consumption

To estimate total and organic food consumption, subjects were asked to complete an optional 264-item organic semi-quantitative FFQ (Org-FFQ) in June 2014. Extensive details have been provided elsewhere (28). For each item, subjects were asked to report the frequency of consumption and the quantity consumed during the last year. For each food item, a five-point Likert-type scale (corresponding to the following modalities: never, rarely, half of the time, often, and always) was also provided, to estimate the frequency of organic food consumption. Organic food intake for each item was obtained by applying a weighting of 0, 0.25, 0.5, 0.75, and 1 to the respective frequency modalities.

The proportion of organic food in the whole diet was calculated by dividing the total organic food consumption by the total food consumption (excluding water).

We also computed the mPNNS-GS (modified Programme National Nutrition Santé-guidelines score), an a priori dietary score reflecting the level of adherence to the French nutritional guidelines; higher scores (max = 13.5) reflect higher dietary quality **Supplemental Table 1** (29).

Selection of the subsample and matching procedure

Of the 33,384 subjects who had completed the Org-FFQ, we selected those who had attended clinical visits with valid dietary data and no missing covariates (N = 5,746). We then selected subjects who had fasted for at least 6 h before the visit, with no history of type I diabetes, Crohn's disease, all types of cancer, neurological diseases, cardiovascular diseases, digestive system diseases (including cirrhosis, hepatitis, celiac disease, and colitis), lupus, spondylolisthesis, and sclerosis (N = 4,598). A propensity matching procedure without replacement was applied to subjects with high or low organic food consumption in their diet (N = 2,351). We obtained two propensity score matched groups of 150 subjects differing on the organic food quantity in the diet.

Blood collection and biomarker analysis

During the clinical visit, a 43-mL fasting blood sample was taken from each participant using a Vacutainer tube, which was distributed into 5 vacutainers containing different kinds of anticoagulants and separators (9-mL tubes containing EDTA K2, one 9-mL tube containing lithium-heparin and two 8-mL plastic tubes containing an inert gel). These vacutainers were used to obtain plasma, serum, buffy coat (for DNA extraction), and RBCs. The tubes were then fractionated into 28 aliquots per subject and stored at a temperature of –80°C at the central laboratory of the biobank (in Paris 13 University). For a given analyte, all measurements were performed in the same laboratory.

Vitamin and mineral biomarker analysis

Plasma concentrations of vitamins A and E as well as 6 carotenoids (α-carotene, ß-carotene, ß-cryptoxanthin, lutein, zeaxanthin, and lycopene) were analyzed by reverse-phase HPLC coupled to diode-array detection (30). Spectra of retinol (λ = 325 nm), α-tocopherol (λ = 292 nm), and carotenoids (λ = 450 nm) were recorded. The quantification of retinol, α tocopherol, and β-carotene was based on calibration curves with each primary standard. For other carotenoids, the extinction coefficients as measured in the solvent mixture, in which the compounds were eluted, were used to establish the corresponding calibration curve. Quality controls were purchased from Chromsystems (vitamins A and E serum control bi-level and ß-carotene serum control bi-level). Between-run precision was 12% for retinol, 13% for α-tocopherol, and 12% for carotenoids.

Plasma concentrations of copper and cadmium were determined using inductively coupled plasma to mass spectrometry (ICP-MS) (31). Plasma was diluted 1:25 with 1% (w/v) HNO_3 prior to ICP-MS determination. Galium (Ga at 650 nmol/L) and rhodium (Rh at 50 nmol/L) were used as internal standards for copper and cadmium determination, respectively. Quality controls were purchased from Recipe (ClinChek serum level 1 and 2). Between-run precision was less than 2.3% for copper and 6.3% for cadmium. Plasma magnesium and iron concentrations as well as transferrin and ferritin were determined using a Dimension Vista 1500 Analyser (Siemens Healthcare Diagnostics). Iron and magnesium were measured using the photometric method. Transferrin was determined using the nephelometric technique and ferritin by chemiluminescent technology (LOCI). Between-run precision was 1.8% at 12.9 µmol/L for iron (level 1) and 3.3% at 1.12 mmol/L for magnesium (level 2) (Liquichek Multiqual, 3 levels, Biorad).

Between-run precision was 2.5% at 29 µg/L for ferritin (Immunoassay Plus, level 2, Biorad) and 2.75% at 2.6 g/L for transferrin (Immunology, level 2, Biorad).

Fatty acid analysis

Plasma fatty acid composition (14:0 to 22:6n–3) was determined. Fatty acids were extracted from a fasting plasma sample and transmethylated with acetyl chloride in methanol (1/19: v/v). Plasma (200 μL) was diluted in 1.9 mL of acetyl chloride/methanol and the mixture was heated at 100°C for 60 minutes. After cooling the mixture, 1 mL of hexane and 1 mL of distilled water were added and the mixture centrifuged at 2,000 rpm for 3 min at 10°C. The hexanic phase was taken and the extraction was conducted twice. Hexanic phases were pooled, diluted with methanol (200 μL of methanol to facilitate drying), and dried under nitrogen. Dried samples were diluted in 200 μL hexane. Fatty acid methyl esters were analyzed by fast GC (Gas Chromatograph Clarus 600, Perkin Elmer) by injecting 0.5 μL of sample in split mode (split ratio 200:1) with a hydrogen flow rate of 10 mL/min (61.4 cm/s and a constant head pressure of 206.8 kPa). A capillary column was used (BP × 70, 10 m × 0.1 mm inner diameter × 0.2 μm film thickness) (SGE International Pty. Ltd.). The temperature program was as follows: initial, 60°C with a 0.5-min hold; ramp, 20°C/min to 200°C, 7°C/min to 225°C with a 1-min hold and then 160°C/min to 250°C with a 1-min hold. The instrument conditions were as follows: the flame ionization detector was set at 280°C; the air and nitrogen make-up gas flow rates were 450 mL/min and 45 mL/min, respectively; the detector sampling frequency was 50 Hz; the run time for a single sample was 13.23 min with a sample injection-to-injection time of 16 min. Between-run precisions were: <2% for C14:0, C16:0, C16:1n–7, C18:1n–9, and C18:2n–6, C18:3 n–3, from 2 to 7% for C20:3n–6, C20:4n–6, C20:5n–3, C22:5n–6, and C22:6n–3, from 7 to 9% for C18:0, C18:3n–6, and C24:1n–9.

Statistical analysis

Selection of the participants (namely, selection of 2 groups of 150 subjects with an organic or nonorganic diet) and matching method (based on propensity score) are described in **Supplemental Table 2**. A

balance diagnostic of the matching method was performed (using SAS macro *%pmdiag*) (32) to provide standardized differences for variables included in the propensity score model as recommended by Ali et al. (33). Characteristics of the participants are presented by group of consumers (organic compared with nonorganic) and compared using the Wilcoxon signed-rank test for matched samples for continuous variables, the McNemar test for binary variables, and conditional logistic regression for categorical variables (>2 modalities variables). Distribution indicators, frequency of detection, and quantification are also presented.

To test for residual confounding in food group consumption between organic and conventional consumers, for biomarkers for which the corresponding nutrient value was available in the conventionally grown food composition database (β-carotene, retinol, iron, magnesium, and some fatty acids), a supplementary model controlling for the nutrient intake was performed using pair-adjusted ANCOVA. For fatty acids, intakes were considered as a percentage of energy intake.

Thus, in the case of similar content for a given nutrient in both organic and conventional food, this adjustment should reduce observed differences due to disparities in food patterns.

As the methodological approach to test for differences between ANCOVA and the matched paired Wilcoxon test do not rely on the same hypothesis, the *P* values may differ between the 2 methods. Therefore, such findings should be interpreted in light of possible modification of the effect by the adjustment. All analyses were performed using version 9.4 of the SAS software (SAS Institute Inc.).

Results

The findings of the balance diagnostic of the matching process are presented in Supplemental Table 1. As expected, no differences were detected overall in health, socio-demographic, or diet factors between organic and nonorganic groups, except for the consumption of mixed dishes (*P* value <0.05). The mean proportion of organic food in the diet was markedly different between groups with an average of 3% of total food intake in the nonorganic group and 67% in the organic group. Participants' characteristics are shown in **Table 1**. Participants were approximately 58 y old, 30% were men, and more than 60% held a high school diploma. The average BMI was 24 kg/m^2 and the overall nutritional quality of the diet, reflected by the mPNNS-GS, was relatively high (8.7 compared with 13.5 max).

No significant differences were found between the 2 groups for α-tocopherol and retinol fasting plasma concentrations as shown in **Table 2**. Organic consumers exhibited higher plasma concentrations of α-carotene, β-carotene, lutein, and zeaxanthin whereas no differences were found for other carotenoids (β-cryptoxanthin and lycopene) (Table 2).

The means of plasma concentrations of minerals and iron-related proteins in organic and conventional groups are shown in **Table 3**. Organic consumers displayed a higher plasma concentration of magnesium and a lower plasma concentration of iron, whereas ferritin and transferrin concentrations as well as the saturation coefficient were comparable. No difference between groups was observed for the other minerals tested, i.e., cadmium and copper.

Plasma fatty acid profiles in both groups are presented in **Table 4**. Organic consumers had lower relative plasma concentrations of palmitoleic acid, γ-linolenic acid, and docosapentaenoic acid and higher linoleic acid concentrations. No differences were found for other individual fatty acid moieties as well as for total SFAs, MUFAs, and total PUFAs. Organic consumers showed a significantly lower C18:3n–6/C18:2n6 ratio and a borderline statistically significant lower C16:1:n–7/C16:0 ratio, compared with nonorganic consumers.

The supplementary models adjusted for corresponding nutrient intake are presented in **Supplemental Table 3**. Overall, findings were unchanged except the iron concentration for which there was no difference detected between organic and conventional groups after adjustment for iron intake. In addition, the difference in α-linoleic and EPA concentrations became statistically significant with lower concentrations in the organic group compared with the conventional group.

Discussion

In the present observational study, we compared various biomarkers of the nutritional status in 2 groups of consumers with discriminant organic food consumption (representing either <10% or >50% of the diet) while controlling for numerous variables including food group consumption through propensity score matching. Significantly higher concentrations of β-carotene, lutein, zeaxanthin, magnesium, and some differences in fatty acid profile were observed in the plasma of high organic consumers.

No differences were detected for vitamin E (α-tocopherol) and vitamin A (retinol) between the 2 groups, whereas carotenoid plasma concentrations were mostly higher in high organic consumers than in low organic consumers. The status of fat-soluble micronutrients depends on many factors affecting their absorption and metabolism, involving (*1*) the state of the food (raw, processed, or cooked), (*2*) the composition of the meal, and (*3*) individual genetic factors (34). Although higher α-tocopherol levels were detected in a few organic foods, such as organic milk (17) and olive oil (35), these sources of intake remained minor compared with the main sources, i.e., vegetable oils and wheat germ/wholegrain cereals. Regarding retinol (vitamin A) concentrations, the main food sources are offal and meat. Vitamin A can also be provided by plant foods as they are good sources of provitamin A-carotenoids (including mainly β-carotene, α-carotene, and β-cryptoxanthin). However, the absence of difference in the overall vitamin A status between the 2 groups of consumers could be explained by the large variation in the inter-individual metabolism of provitamin A carotenoid, which relies on many factors, such as lifestyle, gender, and age as well as genetic variants (36). Interestingly, the higher plasma carotenoid concentration (α-carotene, β-carotene, lutein, and zeaxanthin) in organic consumers evidenced in this study could likely be related to higher intakes of such carotenoids notably provided by organic vegetables (16, 18, 20). In addition, with regard to β-carotene, further adjustment for intake (calculated from conventionally grown food composition) did not modify the findings that argue for a difference in content related to the farming system. In our study, among the fat-soluble micronutrients, the strongest differences were found for lutein and zeaxanthin. Two hypotheses may explain such marked differences: (*1*) lutein and zeaxanthin are xanthophylls (having an oxygen within their structures) known to be better absorbed

TABLE 1 Main characteristics of the sample, $n = 300$, NutriNet-Santé[1]

	Nonorganic group $N = 150$	Organic group $N = 150$	P value[2]
Proportion of organic food in the diet, (%)	3 ± 3	67 ± 13	<0.0001
Age, y	58.71 ± 12.78	58.35 ± 11.69	0.60
Male, %	28%	32%	0.47
Energy intake, kcal/d	1,926.62 ± 561.27	1,994.94 ± 601.57	0.37
mPNNS-GS[3]	8.73 ± 1.76	8.73 ± 1.67	0.59
BMI, kg/m^2	24.18 ± 4.11	24.19 ± 4.02	0.93
Tobacco status, %			0.38
never smoker	48.67	47.33	
former smoker	44.00	40.67	
current smoker	7.33	12	
Physical activity, %			0.85
missing	15	12	
low	25	29	
medium	55	52	
high	55	57	
Vegetarian or vegan diet (yes), %	1.33	2	0.65
Location, %			0.75
rural community	24	25.33	
urban unit with a population smaller than 20,000 inhabitants	11.33	14	
urban unit with a population between 20,000 and 200,000 inhabitants	18.67	20.67	
urban unit with a population higher than 200,000 inhabitants	46	40	
Education, %			0.60
< high school diploma	22	22	
high school diploma	12.67	16.67	
> high school diploma	65.34	61.34	
Income per household unit (€), %			0.77
refused to declare	9.33	7.33	
900–1,200	6.67	8.67	
1,200–1,800	22.67	20	
1,800–2,700	22	26.67	
>2,700	39.33	37.33	
Nutrient intake			
β-carotene, μg/j	4,731.23 ± 3,136.39	4,852.71 ± 2,689.19	0.36
Retinol, g/day	512.84 ± 397.83	506.76 ± 446.20	0.61
Vitamin E, g/day	14.66 ± 8.24	14.35 ± 5.45	0.82
Iron, g/day	14.86 ± 5.50	15.86 ± 5.64	0.10
SFA, g/day	30.34 ± 11.37	32.86 ± 12.45	0.13
MUFA, g/day	33.45 ± 15.63	37.59 ± 14.45	0.004
PUFA, g/day	14.51 ± 8.15	15.06 ± 6.21	0.26
Copper, mg/day	1.98 ± 0.82	2.12 ± 0.75	0.05
Magnesium, mg/day	480.86 ± 168.42	470.20 ± 161.79	0.46
α-linoleic acid, g/day	1.46 ± 1.19	1.67 ± 1.09	0.01
DHA, g/day	0.26 ± 0.27	0.27 ± 0.24	0.37
EPA, g/day	0.21 ± 0.23	0.21 ± 0.21	0.41
Linoleic acid, g/day	11.67 ± 7.09	11.95 ± 5.25	0.36
Arachidonic acid, g/day	0.13 ± 0.06	0.14 ± 0.07	0.30

[1]Values are means ± SD or % as appropriate. mPNNS-GS, modified Programme National Nutrition Sante-Guidelines score.
[2]P value refers to the Wilcoxon signed-rank tests for continuous variables, McNemar's test, or conditional logistic regression for categorical variables.
[3]mPNNS-GS: a dietary index reflecting the level of adherence to French nutritional guidelines. Maximum score = 13.5 points.

than carotenes (34), and (*2*) lutein and zeaxanthin are nonprovitamin A carotenoids that are not enzymatically centered and cleaved in comparison to the provitamin A xanthophyll β-cryptoxanthin. Thus, the higher plasma concentration of lutein/zeaxanthin in organic consumers may likely reflect the higher intake of these 2 xanthophylls elicited by the consumption of organic vegetables which may be richer in these compounds than conventional vegetables (18). The observation of higher concentrations in plasma lutein in organic consumers is in agreement with data of an experimental study conducted in rats given an organic crop regimen (37).

Data comparing the mineral status of organic and nonorganic consumers are scarce. Our study showed a significant slightly higher concentration of plasma magnesium in organic consumers compared with nonorganic consumers. Such observations are in line with some

TABLE 2 Plasma concentrations of α-tocopherol, retinol, and provitamin A carotenoids (α and β-carotene, β-cryptoxanthin) and nonprovitamin A carotenoids (lycopene, lutein, and zeaxanthin) in organic and nonorganic consumers[1]

Concentrations (μmol/L)	Nonorganic group	Organic group	*P* value[2]
α-tocopherol	29.33 (28.27, 30.40)	30.34 (29.28, 31.40)	0.22
Retinol	1.66 (1.60, 1.73)	1.69 (1.63, 1.76)	0.52
α-carotene	0.30 (0.26, 0.34)	0.33 (0.29, 0.37)	0.04
β-carotene	0.96 (0.86, 1.06)	1.09 (1.00, 1.19)	0.04
β-cryptoxanthin	0.27 (0.24, 0.31)	0.30 (0.60, 0.33)	0.50
Lycopene	0.43 (0.39, 0.46)	0.47 (0.44, 0.50)	0.12
Lutein	0.41 (0.38, 0.43)	0.48 (0.45, 0.50)	0.002
Zeaxanthin	0.096 (0.087, 0.105)	0.113 (0.105, 0.122)	0.003

[1]Values are means (95% CI).
[2]*P* value refers to the Wilcoxon signed-rank test for paired data.

reviews (20, 21) reporting higher magnesium content in organic plant foods but to the best of our knowledge, no data in humans are available. Although differences found between groups in the plasma magnesium concentrations are small, they might have some long-term clinical relevance in terms of risk of a metabolic syndrome (38) or prediabetes/type 2 diabetes (39). We did not find any differences regarding the iron status markers between the 2 groups of consumers, which is in line with the limited or no difference in iron content in foods from organic or conventional agriculture (40). Regarding plasma copper concentrations, no difference was found when comparing the 2 groups of individuals. This is concordant with crossover intervention trials using a stable isotope that did not report differences in copper metabolism after consumption of an organic compared with a conventional diet (41). Evidence regarding differences in copper content between organic and nonorganic foods is scarce; however, copper-based sanitary preparations are classically used both in conventional and organic agricultural practices. Factors such as the type of soil could be more significant than the cropping system to predict the mineral content of plants.

Of note, we did not observe any differences in plasma cadmium concentrations between organic and nonorganic consumers. Although data comparing the content of heavy metals in organic and conventional consumers are scarce, the cadmium content of organic crops, compared with conventional ones, has been reported to be noticeably lower, especially in cereals (15) due to differences in fertilizer use for plants growing in the 2 agricultural systems (18, 42). Plant foods are an important source of toxic cadmium for humans but several other exposure routes exist (43), which may explain at least partly the absence of differences found herein in plasma cadmium concentrations in the 2 groups of food consumers.

It is well known that the composition of plasma fatty acids is the result of both the fatty acid intake and the metabolic capacity of the body to metabolize, elongate, and desaturate various fatty acids (44). The plasma fatty acid status observed in organic consumers was mostly comparable to matched nonorganic consumers for the main fatty acids (SFAs, MUFAs, PUFAs) with a few exceptions, such as higher concentrations of linoleic acid and lower concentrations of palmitoleic, γ-linolenic, and docosapentanoeic acids. It is noteworthy that we did not observe any difference between groups for long-chain n–3 fatty acids (EPA and DHA) despite the documented higher concentrations of n–3 fatty acids in organic dairies and meat (17, 19). In the model adjusted for respective intake from conventionally grown food composition data, the EPA concentration was even lower among organic consumers than in conventional ones. It is possible that the relatively small concentrations of n–3 fatty acids present in milk or meat cannot be sufficiently elevated to modify the fatty acid profile at the body level. Another explanation may rely on the low consumption of animal products in the selected sample (with matching based on organic consumers). The higher plasma concentration of linoleic acid could result from some higher intake of vegetable oils rich in linoleic acid in organic consumers and/or a lower rate of conversion into other n–6 moieties. Interestingly, a low linoleic acid

TABLE 3 Plasma concentrations of minerals and proteins related to iron status in organic and nonorganic consumers[1]

Concentrations	Nonorganic group	Organic group	*P* value[2]
Iron, μmol/L	16.21 (15.29, 17.17)	15.24 (14.39, 16.15)	0.05
Transferrin, g/L	2.65 (2.58, 2.71)	2.62 (2.56, 2.68)	0.42
Ferritin, μg/L	71.95 (61.25, 84.53)	73.67 (62.71, 86.55)	0.54
Saturation coefficient	24.50 (22.94, 26.16)	23.28 (21.81, 24.86)	0.30
Magnesium, mmol/L	0.83 (0.82, 0.84)	0.84 (0.83, 0.85)	0.01
Copper, μmol/L	16.74 (16.20, 17.29)	17.15 (16.60, 17.72)	0.64
Cadmium, nmol/L	0.64 (0.61, 0.67)	0.63 (0.60, 0.66)	0.70

[1]Values are means (95% CI).
[2]*P* value refers to the Wilcoxon signed-rank test for paired data.

TABLE 4 Plasma fatty acid levels (% total) in organic and nonorganic consumers[1]

	Nonorganic group	Organic group	*P* value[2]
% Total fatty acids			
C14:0 (myristic acid)	1.006 (0.959, 1.053)	0.975 (0.928, 1.022)	0.72
C16:0 (palmitic acid)	24.895 (24.617, 25.174)	24.590 (24.311, 24.869)	0.24
C16:1n–7 (palmitoleic acid)	2.008 (1.906, 2.110)	1.844 (1.742, 1.946)	0.04
C18:0 (stearic acid)	6.393 (6.234, 6.553)	6.425 (6.265, 6.585)	0.83
C18:1n–9 (oleic acid)	18.679 (18.293, 19.065)	18.754 (18.368, 19.140)	0.66
C18:2n–6 (linoleic acid)	24.732 (24.203, 25.260)	25.650 (25.122, 26.179)	0.02
C18:3n–3 (α-linolenic acid)	0.538 (0.510, 0.566)	0.506 (0.478, 0.533)	0.14
C18:3n–6 (γ-linolenic acid)	0.399 (0.377, 0.422)	0.362 (0.340, 0.385)	0.06
C20:3n–6 (dihomo γ-linolenic acid)	1.903 (1.827, 1.978)	1.812 (1.737, 1.888)	0.12
C20:4n–6 (arachidonic acid)	7.869 (7.628, 8.111)	7.887 (7.646, 8.129)	0.97
C20:5n–3 (EPA)	1.452 (1.322, 1.583)	1.258 (1.128, 1.388)	0.10
C22:5n–3 (docosapentaenoic acid)	0.732 (0.705, 0.758)	0.683 (0.656, 0.709)	0.02
C22:6n–3 (DHA)	3.153 (3.007, 3.299)	3.126 (2.980, 3.272)	0.93
C24:1n–9	1.324 (1.279, 1.369)	1.289 (1.244, 1.335)	0.41
Total SFAs, MUFAs, PUFAs			
SFAs	33.35 (32.98, 33.72)	33.07 (32.70, 33.44)	0.52
MUFAs	23.64 (23.21, 24.07)	23.42 (22.98, 23.85)	0.65
PUFAs	41.79 (41.26, 42.33)	42.29 (41.75, 42.82)	0.55
n–6 PUFAs	35.87 (35.35, 36.38)	36.67 (36.15, 37.18)	0.10
n–3 PUFAs	5.93 (5.65, 6.20)	5.62 (5.35, 5.89)	0.26
Fatty acid ratios (desaturase indexes)			
C16:1:n7/C16:0	0.081 (0.077, 0.085)	0.075 (0.071, 0.079)	0.08
C18:1n9/18:0	3.015 (2.894, 3.136)	3.016 (2.895, 3.137)	0.95
C18:3n6/C18:2n6	0.017 (0.015, 0.018)	0.015 (0.013, 0.016)	0.02
C20:4n6/C20:3n6	4.406 (4.196, 4.616)	4.555 (4.344, 4.765)	0.28

[1]Values are means (95% CI). Fatty acids with plasma concentrations below 1% which were not statistically different between groups are not shown in Table 4 (C15:0, C16:1n–9, C20:0; C20:1; C20:2, C20:3n–3, C21, C22:0, C22:4n–6, C22:5n–6).
[2]*P* value refers to the Wilcoxon signed-rank test for paired data.

factor identified through principal component analysis has been shown to predict metabolic syndrome development over 20 y, independent of smoking habits, physical activity, and BMI (45). The other lower plasma fatty acids found in organic consumers (palmitoleic, γ-linolenic, and docosapentanoeic acids) are metabolic intermediates produced by elongation and/or desaturation of fatty acids from different families; despite their low plasma content, such differences can have some relevance when considering the metabolic pathways involved. Indeed, higher concentrations of palmitoleic acid have been associated with hypertriglyceridemia (46). This is also illustrated by the calculated ratios of precursor/metabolite as representative of specific desaturase enzymatic activities (47). Interestingly, we also found that organic consumers displayed a significantly lower C18:3n6/C18:2n6 ratio and a borderline significantly lower C16:1:n7/C16:0 ratio. The first ratio reflects the activity of the delta 6 desaturase enzyme, and the latter reflects the activity of the delta 9 desaturase enzyme (also called SCD1). Several publications have reported that estimated increases in such enzyme activities are associated with metabolic syndrome (45), a condition with central obesity and several metabolic imbalances considered to be a major risk factor for type 2 diabetes and cardiovascular diseases (48). Despite the strong matching performed herein, the data obtained suggest that the organic consumers exhibit some different fatty acid profiles that are associated with a potentially lower risk of the above-mentioned pathological condition. This appears consistent with our previous observations. We found that, in the NutriNet-Santé cohort, regular organic consumers compared with nonconsumers, have the odds of overweight and obesity reduced by about half in both men and women (2), a risk of developing obesity reduced by 31% (49), and a probability of having a metabolic syndrome reduced by 31% (50).

The current study has some limitations. Similarly to other cohort's participants, volunteers involved in the NutriNet-Santé study are more likely to be more concerned by nutritional and health-related issues than the general population. Thus, the external validation of these findings should be made with caution. Specifically, the participants exhibited particular profiles with regard to socio-demographics and dietary patterns (1).

In addition, food consumption was evaluated using a self-administered FFQ that is susceptible to measurement errors leading to a probable overestimation of the consumption in particular of organic food (2). Another limitation relies on the fact that among organic consumers, the total mean share of organic foods was only 67%, i.e., the diet was not entirely composed of organic foods. This could limit the possible differences in the observed impacts of food production practices as organic consumers also partly consumed conventional foods. Blood vitamin C concentration was not estimated due to methodological constraint related to biological collection.

Finally, despite a wide range of variables accounted for in the propensity score matching procedure, we cannot rule out possible residual confounding between groups of consumers (organic and nonorganic) especially as we are focusing on food group consumption in the matching procedure and not on specific food.

We also did not consider genetic factors that can play a role in nutrient absorption and metabolism.

Important strengths should also be mentioned. We used accurate biological measures obtained in expert laboratories. The use of the Org-FFQ permitted the gathering of detailed data on food consumption, including information on the usual proportion coming from organic sources of several food groups, within the overall diet. The use of a wide range of covariates, including socio-demographic, health conditions, and lifestyle variables, enabled us to precisely characterize the individuals selected in our study. Furthermore, the reasonable sample size enabled us to conduct analyses with sufficient statistical power. The extensive matching made to compare the nonorganic consumers with organic consumers allowed us to evaluate the impact of food composition elicited by agriculture practices on some traits of the nutritional status of human adults, independently of numerous variables including food pattern. It is the first comparative study that has been performed based on such an approach that considers the actual level of consumption. Nevertheless, this matching procedure that blunts numerous differences in lifestyles, dietary patterns, and socio-economic traits of nonorganic consumers compared with organic ones does not allow extrapolation of the present results to the actual characteristics of nonorganic consumers exhibiting different dietary patterns (2).

In conclusion, the present study allowed the estimation of the possible impacts of food composition variations due to agricultural practices on some traits of nutritional status. We found that high consumption of organic foods, compared with low, within the same dietary pattern, could modulate the plasma concentrations of magnesium but not iron, copper, or the heavy metal cadmium. Some differences were detected for some carotenoids such as α-carotene, β-carotene, lutein, and zeaxanthin but not vitamins A and E, lycopene or β-cryptoxanthin and for some fatty acid relative concentrations such as linoleic acid, palmitoleic, γ-linolenic and docosapentanoeic acids and some fatty acid desaturase indexes. The clinical effects of such differences need further investigation by evaluating long-term health effects.

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