# Association between organic food consumption and Metabolic Syndrome: cross-sectional results from the NutriNet-Santé study

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**Abstract**

**Purpose:** Metabolic Syndrome (MetS), a multicomponent condition, is a cardiovascular disease predictor. Although exposure to agricultural pesticides has been suggested as a potential contributor to the rising rates of obesity, type 2 diabetes and other features of metabolic disorders, no studies have focused on the association between consumption of organic food (produced without synthetic pesticides) and MetS. We aimed to investigate the cross-sectional association between organic food consumption and MetS in French adults to determine whether it would be worth conducting further studies, particularly large prospective and randomised trials.

**Methods:** A total of 8,174 participants from the NutriNet-Santé study who attended a clinical visit and completed an organic food frequency questionnaire were included in this cross-sectional analysis. We evaluated the association between the proportion of organic food in the diet (overall and by food group) and MetS using Poisson regression models while adjusting for potential confounders.

**Results:** Higher organic food consumption was negatively associated with the prevalence of MetS: adjusted prevalence ratio was 0.69 (95%CI: 0.61, 0.78), when comparing the 3rd tertile of proportion of organic food in the diet with the first one (p-value <0.0001). Higher consumption of organic plant-based foods was also related to a lower probability of having MetS. In addition, when stratifying by lifestyle factors (nutritional quality of the diet, smoking status, physical activity), a significant negative association was detected in each subgroup (p-values <0.05), except among smokers.

**Conclusions:** Our results showed that a higher organic food consumption was associated with a lower probability of having MetS. Additional prospective studies and randomised trials are required to ascertain the relationship between organic food consumption and metabolic disorders.

**Keywords**: metabolic syndrome, metabolic traits, organic food consumption, dietary pattern

**Abbreviations**: BMI, Body Mass Index; CI, Confidence Intervals; CNIL, National Commission on Informatics and Liberty; DBP, Diastolic Blood Pressure; EFSA, European Food Safety Authority; ENNS, French National Nutrition and Health Survey; HDL, High Density Protein; IRB, Institutional Review Board of the French Institute for Health and Medical Research; INSEE, French National Institute of Statistics and Economic Studies; IPAQ, International Physical

Activity Questionnaire; LDL, Low Density Protein; MetS, Metabolic Syndrome; mPNNS-GS, modified Programme National Nutrition Guideline Score; Org-FFQ, organic Food Frequency Questionnaire; Persistent Organic Pollutants, POP; PUFA, Polyunsaturated Fatty Acids; PR, Prevalence Ratios; SBP, Systolic Blood Pressure

**Introduction**

Metabolic Syndrome (MetS), a collection of metabolic abnormalities, is a clinical condition used to identify individuals at increased risk of cardiovascular mortality early in the disease process [1–4]. Features of MetS combine dyslipidaemia, elevated blood pressure and glycaemia, and abdominal obesity [5]. The prevalence of MetS reached 25% of the population in Europe [6], in line with the rising rate of obesity and type-2 diabetes. In France, where the MetS appeared to be lower than in most industrialised countries, MetS prevalence would be comprised between 14.1% and 21.1% depending on definitions used, according to the French National Nutrition and Health Survey (ENNS) carried out in 2006-2007 [7].

Although the aetiology of MetS is complex, some major environmental risk factors are well-known, and include diet [8–12], physical activity [13] or tobacco smoking [14]. While the role of dietary patterns (e.g. vegetarian or Mediterranean diets [10–12, 15]) on the risk of onset of MetS has been thoroughly investigated, no studies have taken into consideration the mode of food production (i.e. organic or conventional farming practices) in the association between diet and metabolic status.

Consumers are increasingly concerned about what they eat and about the potential harmful effects of pesticide residues on their health [16–18], and as a result, more and more are turning to organic food [19], since the use of synthetic pesticides and chemical fertilisers is prohibited by organic farming regulations [20]. The latest European Food safety Authority (EFSA) report on pesticide residues in food [21] indicates a lower dietary exposure to pesticides via organic foods than via conventional crop-based foods. In addition, a cross-over Australian study showed a drastic (about 90%) reduction in urinary organophosphate exposure in adults after a change toward a 80% organic food-based diet [22], in line with several studies previously conducted among children [23–25]. Existing systematic reviews and meta-analyses comparing organically and conventionally produced foods also pointed differences in nutritional composition amongst which higher content in polyphenol compounds [26–29], antioxidants [26, 30–33] and vitamins [26–28, 30] in organic crops as well as the beneficial fatty acid profiles in organic dairy products [27, 31, 32]. They also found lower concentrations of nitrate [26, 27, 30, 33] and lower levels of iodine and selenium in organic milk [32]. Significantly lower concentrations of cadmium in organic food have also been reported [26] while no differences have been observed for other toxic metals [28]. Although these findings overall argue for a more favourable nutritional composition of organic products compared to conventional alternatives, the clinical relevance of these differences, however, remains uncertain.

The study of the impact of organic food consumption on metabolic status is of high interest as several epidemiological studies have suggested a link between pesticide exposure and metabolic disorders [34–37]. In addition to well-established contributors to cardio-metabolic diseases (such as lack of physical activity and energy overconsumption), newly identified potential risk factors include endocrine disrupting pesticides such as organochlorides, organophosphates, carbamates and pyrethroids [38, 39]. Besides, various nutritional factors - for which differences have been observed between organic and conventional products - have been linked to a decreased risk for some cardiovascular outcomes (such as omega-3 polyunsaturated fatty acids (PUFA) [40, 41], polyphenols [42], several metal pollutants and more specifically cadmium [43] and more controversially nitrate and nitrite [44, 45]).

Nonetheless, to our knowledge, the link between a diet largely based on organic foods (namely with a potential low pesticide exposure and potentially a more favourable nutritional profile) and metabolic status has never been explored. Studies evaluating the associations between obesity and organic food consumption are scarce ; only three studies (two of which were conducted in the NutriNet-Santé cohort) have shown that regular organic food consumption was negatively related to obesity [46–48].

Hence, the objective of the present study was to examine the specific relationship between organic food consumption (overall and by food groups) and the presence of MetS using a cross-sectional design, among a large sample of adults residing in France from the NutriNet-Santé study. Through this exploratory analysis, we aimed to provide some evidence in the field of organic food consumption and metabolic disorders to determine whether this particular domain merits further investigation.

## Methods

*Study population and design*

This study is based on the NutriNet-Santé study data, an ongoing observational web-based cohort study launched in May 2009. Its overall aim is to investigate the relationships between nutrition and health as well as the determinants of dietary behaviours and nutritional status. The NutriNet-Santé study's rationale, design, and methodology have been described elsewhere [49]. In brief, upon enrolment in the NutriNet-Santé study and each year thereafter, participants are asked to provide information on sociodemographic and various lifestyle factors, health status, physical activity, anthropometric factors, and diet. The NutriNet-Santé 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 number 0000388FWA00005831) and the National Commission on Informatics and Liberty (CNIL numbers 908450 and 909216). Electronic informed consent was obtained from each participant (EudraCT no.2013-000929-31).

Additionally, in 2011-2014, the NutriNet-Santé participants were invited, on a voluntary basis, to attend a visit for biological sampling and clinical examination in one of the local centres throughout France. Electronic and paper written informed consents were obtained from all participants attending the visit. All procedures were approved by the 'Consultation Committee for the Protection of Participants in Biomedical Research' (C09-42 on May 5th 2010) and the CNIL (n° 1460707).

*Data collection*

<u>Dietary data</u>

Food and organic food consumption were assessed through a validated self-administered semi-quantitative food frequency questionnaire [50], to which additional questions about frequencies of consumption of organic foods were added (Org-FFQ). The Org-FFQ has been described in details elsewhere [51]. Briefly, the Org-FFQ included 264 food and beverage items, coupled for the most part with specified serving sizes. The questionnaire also included photographs for some specific categories that are not usually consumed in predetermined portion. For each food item, participants were asked to provide their consumption frequency over the past year (through a drop-down list including yearly, monthly, weekly or daily units) as well as the quantities consumed. In addition, the frequency of organic food consumption was assessed using the following statement: ‘How often was the product of organic origin?’. Answers modalities were assessed by a 5 frequency-categories scale with modalities from ‘never’ to ‘always’ (never, rarely, half of time, often and always).

Modalities of frequencies of organic food consumption were translated into quantitative data by attributing a weight of 0, 0.25, 0.5, 0.75 and 1 to the respective following categories: ‘never’, ‘rarely’, ‘half the time’, ‘often’ and ‘always’. Thus, we calculated the proportion of organic food in the whole diet by dividing the total organic food consumption (in grams per day) out of the total consumption without water (in grams per day). We also calculated the proportion of organic food in 16 main food groups among consumers. Nutrient intakes were assessed using a generic food composition database (independent of the food production - organic or conventional), specifically developed for the items of the Org-FFQ, which was based on the NutriNet-Santé original food composition table that includes more than 3000 items [52].

In addition, we computed the mPNNS-GS (modified Programme National Nutrition Santé Guideline Score), a diet quality score based on adherence to the French dietary guidelines excluding the physical activity component [53].
Information on anteriority of organic food consumption (referring to the number of years for which participants have been consuming organic products) was collected via a questionnaire pertaining to attitudes towards organic food administered in July 2014.

Covariates

At baseline and during follow-up phases, self-administered questionnaires were used to collect information on sociodemographic factors and lifestyle, and medication use, including sex, age, education (highest degree achieved), marital status, number of children, smoking habits, income, place of residence, physical activity (as assessed by the International Physical Activity Questionnaire (IPAQ) [54, 55]), and antidiabetic, antihypertensive and lipid-lowering medications. Monthly income per household unit was calculated using INSEE (French National Institute of Statistics and Economic Studies) calculation [56].

Clinical data assessment

During the clinical examination, anthropometrics and blood pressure were measured by trained personnel using standardised protocols. Systolic and diastolic blood pressures (SBP and DBP respectively) were measured 3 times at 1-minute intervals in a seated position after lying down for 5 minutes using an automatic validated device (HEM-7015IT; OMRON, Rosny-sous-Bois, France). Mean values were calculated for the analyses. The clinical examination also comprised measures of weight, height, and waist circumference. Weight was measured once using an electronic scale (BC-418MA; TANITA, Tokyo, Japan) with participants only wearing underwear and barefoot. Height was measured once with a wall-mounted measuring rod. Body mass index (BMI in $kg/m^2$) was calculated. Waist circumference was measured as the circumference midway between the lower ribs and iliac crests.

Biological data assessment

During the visit, blood samples were collected after at least a 6h-fast period and centralised and analysed at a single laboratory (IRSA, Tours, France). Total serum cholesterol (cholesterol oxidase C8000, Abbott), HDL-cholesterol (High Density Protein – cholesterol) (direct accelerator C8000, Abbott), serum triglycerides (glycerol kinase C8000, Abbott) and fasting blood glucose were measured (hexokinase on C 8000 automat, Abbott, Suresnes, France). LDL-cholesterol (Low Density Protein – cholesterol) was calculated using the Friedwald formula [57].

Definition of MetS

Individuals defined as presenting MetS were those having any three of the following five criteria according to the 2009 interim consensus statement [5]:

- abdominal obesity (waist circumference ≥94 cm for men and ≥80 cm for women),
- elevated blood pressure (SBP/DBP ≥130/85 mmHg or antihypertensive medication),
- elevated triglyceridemia (≥150 mg/dL or fibrate medication),
- low HDL-cholesterolemia (<40 mg/dL for men or <50 mg/dL for women),
- elevated glycaemia (fasting glycaemia >100 mg/dL or antidiabetic medication).

*Statistical analysis*

Among respondents to the Org-FFQ (n=33,384), we selected those who attended the medical visit (n=9,373), with valid anthropometric and biological data (n=8,354), with available covariates, which led to a final sample of 8,174 individuals (2,602 men and 5,572 women).

Participant characteristics (sociodemographic and dietary traits) were compared across tertiles of proportion of organic food in the diet using ANCOVA with linear contrast (continuous variables) and Cochran-Mantel-Haenszel trend test (categorical variables). Values are reported as means with standard deviations (SD) or percent as appropriate. Based on the source population (respondents to the Org-FFQ), excluded and included participants were compared using Mann-Whitney U tests and $Chi^2$-tests.

A total of 16.7% of subjects met the criteria for MetS (23.8% in men and 13.4% in women) in the study sample. Since the occurrence of the dependent variable exceeded 10%, odds ratios from standard logistic regressions could not be considered as appropriate proxies for relative risks [58]. We therefore used an alternative method recommended by Zou et al. [59] based on Poisson regression models with robust errors to evaluate the association between tertiles of proportion of organic food in the diet, as well as tertiles of proportion of organic food in 16 food groups, and having MetS (binary dependent variable). The lower tertile of proportion of organic food in the diet was considered as reference category. We reported Prevalence Ratios (PR) and 95% Confidence Interval (95% CI) as well as P-values from linear contrast.

A first model was crude (model 1). A second model (main model, model 2) was adjusted for age, sex, educational level, monthly income, physical activity, smoking habits, season of blood sampling, time lag between organic food questionnaire completion and clinical visit, occupational status, location, energy intake and overall dietary quality (reflected by the mPNNS-GS as a continuous variable). A supplementary model (model 3) was further controlled for BMI to determine the association of organic food consumption with MetS beyond adiposity. An additional model (model 4) was also performed by adding to the main model the anteriority of organic food consumption (as a categorical variable: non-organic food consumption, organic food consumption for less than 5 years, organic food consumption for more than 5 years). The models pertaining to the association between the proportion of organic food in several food groups and MetS were additionally adjusted for the corresponding food group consumption.

Furthermore, in an attempt to distinguish the role of organic food from that of potential correlated lifestyles, we investigated the association between the proportion of organic food in the diet (as a continuous variable) and having MetS stratified by various behavioural factors: overall nutritional quality of the diet (using tertiles of mPNNS-GS), smoking habits and physical activity.

ANCOVA models were also performed to evaluate the relationship between the proportion of organic food in the diet and various metabolic traits (fasting blood glucose, waist circumference, SBP, DBP, serum triglycerides and HDL-cholesterol) among sub-samples who were not taking any related medications for the specific outcome. To improve normality, anthropometric variables and biomarkers were logarithmically transformed before analysis and adjusted geometric means (95%CI) across tertiles of proportion of organic food in the diet are provided. Same confounding covariates as those previously described for MetS in model 2 were used.

All tests of significance were two-sided, and the type I error was set at 5%. All analyses were performed using SAS software (version 9.4, SAS Institute, Inc.).

## Results

Participants included in our study were older (58.16 ± 12.34 y vs. 53.20 ± 14.07 y), more often men (32% vs. 25%) and had more frequently a monthly income higher than 2700 € per household unit (32% vs. 39%) than respondents to the Org-FFQ excluded from the analysis (data not tabulated).

*Characteristics of the participants*

Main characteristics of the study sample across tertiles of proportion of organic food in the diet are presented in **Table 1**. Low organic food consumers (tertile 1) consumed no or very little organic food while, in tertile 3, organic food made up, on average, 0.62 (0.18) of the diet. Compared to low organic food consumers, high organic food consumers were less often men, younger and more often highly educated. No statistically significant difference was observed concerning monthly income per household unit across tertiles of proportion of organic food in the diet. High organic food consumers also lived less frequently in a population-dense urban unit (>200 000 inhabitants) than low organic food consumers. They were also more often never smokers and more frequently presented a high physical activity. Higher organic food consumption was also associated with a higher overall nutritional quality of the diet, lower alcohol consumption and a lower body mass index.

*Association between the proportion of organic food in the diet and MetS*

**Table 2** shows the association between tertiles of proportion of organic food in the diet and MetS. In the main model (model 2), higher organic food consumption was associated with a lower probability of having MetS ($PR_{tertile3\ vs.\ tertile\ 1}$=0.69, 95%CI=0.61-0.78; p for linear contrast <0.0001). The association was attenuated but persisted even after controlling for BMI ($PR_{tertile3\ vs.\ tertile1}$=0.86, 95%CI=0.76-0.98; p for linear contrast =0.02) (model 3) or for the anteriority of organic food consumption ($PR_{tertile3\ vs.\ tertile1}$=0.69, 95%CI=0.59-0.80; p for linear contrast <0.0001) (model 4).

*Association between the proportion of organic food according to food groups and MetS*

**Table 3** shows a marked negative association between an increased consumption of products from organic origin for plant food groups (including fruit and vegetables, starchy foods, whole-grain products and oil; all p for linear contrast ≤0.0005) as well as sweetened foods and non-alcoholic beverages (p for linear contrast <0.0001) and MetS. Similar results were observed, but to a lesser extent, for eggs, dairy products and fast food. In contrast, no significant association was found in the cases of seafood and meat, poultry and processed meat (p>0.05).

*Association between the proportion of organic food in the diet and metabolic components*

In the fully adjusted model, among subgroups of individuals who were not taking any related medication for the specific outcome, higher organic food consumption was significantly associated with lower fasting blood glucose, waist circumference, SBP and DBP, and triglycerides (all p for linear contrast <0.05), but not with HDL-cholesterol (**Table 4**).

*Association between the proportion of organic food in the diet and MetS according to overall dietary quality, smoking status and physical activity*

Stratified analyses are illustrated in **Figure 1**. After stratifying by tertiles of the mPNNS-GS (reflecting overall dietary quality), higher organic food consumption (modelled as a continuous variable) was negatively associated with MetS, regardless the level of dietary quality, when adjusting for sociodemographic and lifestyle variables. Similar results were obtained when stratifying by other lifestyle factors including smoking status and physical activity level, except among current smokers.

**Discussion**

In this cross-sectional study, we observed that a higher organic food consumption (i.e. a proportion of organic food in the diet >38%, corresponding to the 3$^{rd}$ tertile) was associated with a lower probability of having MetS as well as lower levels of glycaemia, blood pressure, triglycerides, and waist circumference after adjustment for the major known confounding factors. No significant association was observed with the HDL-cholesterol. The negative association was observed, in particular, when the proportion of plant food from organic sources increased, and persisted among different subgroups of the study sample.

To the best of our knowledge, no studies had previously investigated the specific association between organic food consumption and metabolic disorders, and MetS in particular.

Some data is however available regarding anthropometric traits of organic food consumers. A study conducted in Germany showed that buyers of organic food exhibited lower body weight compared to non-buyers [47]. However, the primary aim of that study was descriptive and did not take into account potential confounding factors. Hence, lower body weights among frequent buyers of organic foods could be attributable to healthier lifestyles rather than to differences in consumption of organic and conventional foods. Previous cross-sectional findings from the NutriNet-Santé have also highlighted a negative association between regular organic food consumption and BMI in fully adjusted models [46]. More recently, in a prospective study carried out in the same cohort [48], we showed, after controlling for major confounders, that an increase of self-reported organic food frequency was associated with a significantly lower risk of overweight and obesity.

In the present work, associations between high organic food consumption and the prevalence of MetS remained significant even after carefully adjusting for a wide range of confounders (including overall dietary quality, physical activity, sex, and BMI).

A potential hypothesis explaining, at least in part, our findings may be the reduced dietary exposure of high organic food consumers to synthetic pesticides. Indeed, as European Union legislation allows only a very limited number of natural pesticides to be used in organic food production, the occurrence of synthetic pesticide residues in organic crops is much lower than in conventional crops [21, 26]. In the last report of the EFSA, 15.5% of organic foods contained pesticide residues (0.8% above the Maximum Residue Level) vs. 44.4% of conventional products (2.7% above the Maximum Residue Level) [21]. It can thus be hypothesised that individuals who consume a high level of organic food in their diet would reduce their overall dietary exposure to pesticides, as highlighted in studies conducted in adults [22, 60] or in children [23, 24].

Several epidemiological studies have suggested a link between pesticide exposure, obesity and metabolic disorders. Our findings may be interpreted in light of some studies which showed, for instance, a positive association between an increased risk for abnormal glucose regulation and exposure to pyrethroids [61]. The findings from the Agricultural Health cohort study, conducted in 30,000 farmers in the US, suggested that long-term occupational exposure, in particular organochlorine and organophosphate insecticide exposure, could be associated with increased risk of developing diabetes [62]. However, epidemiological studies about the impact of exposure to organophosphorus compounds (widely used in agriculture) in the general population, on metabolic status are lacking.

Among potential mechanisms, it has been reported that exposure to endocrine disruptors such as various currently used pesticides, i.e. organophosphates and pyrethroids would impact glucose homeostasis and fat metabolism [38, 63]. Organophosphorus compounds would disrupt carbohydrate homeostasis, resulting in elevated serum glucose levels [64]. Among disrupting effects of the organophosphates, mechanistic pathways may involve oxidative damage and inflammatory cytokines, possibly leading to compensatory responses accompanied with reduced insulin signalling in insulin sensitive organs [63].

This seems in agreement with our findings concerning biomarkers related to glucose and fat metabolism, namely glycaemia and triglyceride levels. As regards blood pressure, to our knowledge, no studies have investigated the specific association between exposure to widely used pesticides and blood pressure. Thus experimental and epidemiological data focusing on effects of organophosphate, pyrethroid or carbamate exposure and their synergistic association to hypertension risks are necessary. We did not find a significant higher level of HDL-cholesterol in individuals with higher organic food consumption after controlling for main confounding factors, in line with the few available data regarding dietary pesticide exposure and this specific biomarker.

Moreover, in addition to the potential effects of dietary pesticide exposure, mainly through conventional plant-food consumption, on cardiometabolic disorders, our results can also be interpreted in light of findings of a study carried out in rats which found overall better health and physiological parameters among animals fed with an organic diet, of which higher concentrations of polyphenols, plasma glucose, leptin or insulin-like growth factor 1 [65].

In addition, our analyses interestingly showed a negative association between higher consumption of plant-based foods from organic origin and MetS while no association was detected in the case of meat, poultry and processed meat.

These results can be considered in the light of the EFSA report [21] which showed that about half plant food samples were contaminated by pesticide residues and that Maximum Residue Levels were frequently exceeded for some plant-based products (e.g. strawberries, lettuce, apples or oats) while this was not the case for animal-based foods like pork meat or cow milk. Thus, conventional foods from plant origin would be the major contributors to current dietary pesticide exposure, unlike animal-based foods.

Interestingly, we found significant negative associations between MetS prevalence and increasing consumption of dairy products and eggs. These findings can be interpreted in light of studies reporting more favourable fatty acid compositions in organic dairy products [31, 32]. Indeed, recent meta-analyses have indicated that organic milk [32], and potentially organic meat [66], contained a higher amount of omega-3 fatty acids, which are main components of a beneficial diet for the cardiovascular system, compared to conventional products. Switch from conventional to organic dairy and meat products could therefore lead to higher amounts of omega-3 fatty acids and in turn positively affect cardiometabolic status. However, it is difficult to conclude to the nutritional significance of these differences on health, as these increases remain probably modest and their effects unknown.

It should be borne in mind that high organic food consumers are high consumers of fruit, vegetables and whole-grain products [47, 53]. Plant-based diets have also been associated with reduced risk of having MetS [10, 15]. In order to take into account the healthier dietary patterns of high organic food consumers, as well as other potentially healthy lifestyle factors that play a role in the development of MetS, we conducted stratified analyses, allowing to partially overcome the 'nutritional' role of dietary patterns. Except in smokers, a higher proportion of organic food in the diet was negatively related to MetS, whatever the subgroups considered. In particular, the association was observed across all subgroups. Among smokers, no association was observed between organic food consumption and MetS. One explanation might be that the tobacco risk factor prevails, and in turn, in this 'high risk subgroup', the consumption of organic food could play a minor role. Another explanation might be the relatively small size of that specific subgroup. The non-significant result may therefore be related to limited statistical power.

*Limitations and strengths*

A major limitation of this study includes its cross-sectional design, restricting causal inference. Although we adjusted for a large number of cofounding factors including variables related to healthy lifestyles, we cannot omit the residual confounding due to the specific profiles of high organic food consumers (36,37). In addition, the NutriNet-Santé participants are more interested in nutrition and health topics than the general population. Specifically, the participants of the NutriNet-Santé study exhibit specific sociodemographic profiles [67] and healthier dietary habits [68] than the general population. Besides, organic food consumption was assessed using a self-administered food frequency questionnaire which is prone to measurement error. This has also probably led to an overestimation of the consumption in particular for organic food [51]. Finally, we did not have data regarding genetic factors that can play a role in the onset of MetS. Caution is therefore needed when generalising the results.

Important strengths should also be acknowledged. We used accurate biological measures (performed in a single laboratory) and clinical data (assessed by trained technicians using standardised procedures). The use of the Org-FFQ permitted to obtain 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 covariables, including sociodemographic and lifestyle variables, enabled us to precisely characterise the individuals of our study. Furthermore, the large size of the sample enabled us to conduct stratified analyses with a sufficient statistical power, and to have a wide diversity of profiles.

*Conclusion*

In conclusion, our results provide the first insights into the undocumented research field of metabolic health and organic food consumption. Our findings show that the highest the consumption of organic food, the lowest the probability of having MetS. The associations that were observed merit future investigation, and bolster the argument for the conduction of well-designed randomised controlled trials. Besides, further prospective research based on accurate data with regard to the nature of foods consumed is also needed to confirm these findings and assess the long-term effects of organic food consumption on metabolic disorders. In a context of tremendous growth of organic food consumption and where cardiovascular diseases remain the first cause of mortality worldwide, these findings could be of major interest to drive the design of future public health policies.

**Contribution statement**

SH, PG, DL and EKG conceived and designed research; JB performed the statistical analysis and wrote the article; JB, HL, SA, CJ, BA, SH, MT, DL, PG and EKG were involved in revising the work critically for important intellectual content; JB had primary responsibility for final content. All authors read and approved the final manuscript.

**Conflicts of interest**

None of the authors declare any conflicts of interest.

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**Table 1. Main characteristics of the sample across tertiles of proportion of organic food in the diet, n=8,174, NutriNet-Santé study[a]**

| Characteristics | Tertile 1 (*n=2,724*) | Tertile 2 (*n=2,725)* | Tertile 3 (*n=2,725)* | P trend[b] |
|---|---|---|---|---|
| Proportion of organic food in the whole diet (ratio) | 0.04 (0.04) | 0.24 (0.07) | 0.62 (0.18) | <0.0001 |
| Men (%) | 38.99 | 30.53 | 25.98 | <0.0001 |
| Age (y) | 59.03 (12.84) | 57.96 (12.41) | 57.50 (11.71) | <0.0001 |
| Educational level (%) | | | | <0.0001 |
| *Primary* | 25.48 | 23.05 | 20.99 | |
| *High school diploma* | 14.72 | 14.09 | 13.69 | |
| *University level or equivalent* | 59.80 | 62.86 | 65.32 | |
| Occupational status (%) | | | | <0.0001 |
| *Retired* | 56.06 | 51.01 | 47.05 | |
| *Employees* | 9.14 | 9.69 | 9.69 | |
| *Intermediate profession* | 10.61 | 12.48 | 12.4 | |
| *Managerial staff* | 15.16 | 19.60 | 20.37 | |
| *Never employed* | 7.60 | 6.24 | 8.55 | |
| *Self employed* | 1.43 | 0.99 | 1.94 | |
| Monthly income per household unit (%) | | | | 0.49 |
| *Refuse to declare* | 4.70 | 4.18 | 5.21 | |
| *900-1200 €* | 8.26 | 6.72 | 7.78 | |
| *1200-1800 €* | 20.15 | 19.63 | 20.15 | |
| *1800-2700 €* | 27.90 | 28.77 | 29.43 | |
| *>2700 €* | 38.99 | 40.70 | 37.43 | |
| Location (%) | | | | <0.0001 |
| *Rural community* | 16.45 | 18.79 | 21.98 | |
| *Urban unit with a population smaller than 20 000 inhabitants* | 13.99 | 14.13 | 16.11 | |
| *Urban unit with a population between 20 000 and 200 000 inhabitants* | 15.16 | 16.59 | 16.00 | |
| *Urban unit with a population higher than 200 000 inhabitants* | 54.41 | 50.50 | 45.91 | |
| Smoking habits (%) | | | | 0.03 |
| *Never smoker* | 46.26 | 47.63 | 50.61 | |
| *Former smoker* | 44.35 | 43.89 | 43.08 | |
| *Current smoker* | 9.40 | 8.48 | 6.31 | |
| Physical activity level (%) | | | | <0.0001 |
| *Low* | 20.30 | 17.03 | 14.72 | |
| *Moderate* | 40.42 | 42.06 | 39.60 | |
| *High* | 39.28 | 40.92 | 45.69 | |
| Time lag between dietary data collection and visit (months) | 23.90 (11.38) | 22.99 (11.39) | 22.17 (11.36) | <0.0001 |
| mPNNS-GS (/13.5) | 8.35 (1.79) | 8.65 (1.71) | 8.86 (1.78) | <0.0001 |
| Alcohol consumption (g/d) | 127.77 (173.76) | 121.85 (159.03) | 98.07 (121.78) | <0.0001 |

| | | | | |
|---|---|---|---|---|
| Energy intake (kcal/d) | 2032.06 (644.43) | 2021.03 (609.60) | 2027.76 (617.92) | 0.80 |
| Carbohydrates[c] | 39.40 (7.50) | 39.27 (7.40) | 39.45 (7.43) | 0.81 |
| Lipids[c] | 40.70 (6.88) | 41.20 (6.92) | 42.38 (7.27) | <0.0001 |
| Proteins[c] | 19.51 (3.58) | 19.13 (3.45) | 17.80 (3.48) | <0.0001 |
| BMI (kg/m²) | 25.14 (4.52) | 24.69 (4.34) | 23.87 (3.99) | <0.0001 |

Abbreviations: BMI, Body Mass Index.

[a] Values are means (SD) or percent, as appropriate.

[b] Linear contrast test from ANCOVA (continuous variables) or Mantel-Haenszel Chi² trend-test (categorical variables).

[c] As a percentage of alcohol-free energy intake.

**Table 2. Association between tertiles of proportion of organic food in the diet and MetS, n=8,174, NutriNet-Santé study[a]**

| | Proportion of organic food in the whole diet (ratio) | | | P for linear contrast |
|---|---|---|---|---|
| | Tertile 1<br>[0.00-0.12[ | Tertile 2<br>[0.12-0.38[ | Tertile 3<br>[0.38-1.00] | |
| N | 2,724 | 2,725 | 2,725 | |
| Cases N (%) | 565 (20.7) | 469 (17.2) | 329 (12.1) | |
| *Model 1* | 1 (ref) | 0.83 (0.74, 0.93) | 0.58 (0.51, 0.66) | <0.0001 |
| *Model 2* | 1 (ref) | 0.91 (0.82, 1.02) | 0.69 (0.61, 0.78) | <0.0001 |
| *Model 3* | 1 (ref) | 0.98 (0.88, 1.09) | 0.86 (0.76, 0.98) | 0.02 |
| *Model 4[b]* | 1 (ref) | 0.94 (0.83, 1.06) | 0.69 (0.59, 0.80) | <0.0001 |

Abbreviations: MetS, Metabolic Syndrome; ref, reference.

[a] Values are prevalence ratios, PR (95%CI) for the relation between the proportion of organic food as a categorical variable (tertiles) and Metabolic Syndrome modelled as a binary variable.

Model 1 is unadjusted. Model 2 is adjusted for age, sex, educational level, monthly income, physical activity, smoking habits, season of blood sampling, time lag between organic food questionnaire completion and clinical visit, occupational status, location, energy intake and overall dietary quality (estimated by the mPNNS-GS as a continuous variable). Model 3 is Model 2 further adjusted for BMI. Model 4 is Model 2 further adjusted for the anteriority of organic food consumption.

[b] As the questionnaire from which the question was extracted was optional, sample size was 6,911.

**Table 3. Association between tertiles of proportion of organic food according to food groups and MetS, NutriNet-Santé study[a]**

| | N[b] | Proportion of organic food of the food group (ratio) | | | P for linear contrast |
|---|---|---|---|---|---|
| | | Tertile 1 | Tertile 2 | Tertile 3 | |
| Fruit and vegetables (including juices and soups) | 8,169 | 1 (ref) | 0.95 (0.85, 1.06) | 0.78 (0.69, 0.89) | <0.0001 |
| Starchy foods | 8,170 | 1 (ref) | 1.00 (0.90, 1.11) | 0.69 (0.61, 0.79) | <0.0001 |
| Whole-grain products | 6,850 | 1 (ref) | 0.99 (0.87, 1.12) | 0.78 (0.68, 0.90) | 0.0005 |
| Oil | 8,093 | 1 (ref) | 0.97 (0.87, 1.09) | 0.74 (0.65, 0.84) | <0.0001 |
| Seafood | 7,963 | 1 (ref) | 0.89 (0.77, 1.03) | 1.02 (0.92, 1.13) | 0.75 |
| Meat, poultry, processed meat | 7,939 | 1 (ref) | 1.06 (0.95, 1.19) | 0.98 (0.87, 1.11) | 0.76 |
| Eggs | 7,907 | 1 (ref) | 0.92 (0.82, 1.04) | 0.83 (0.73, 0.93) | 0.002 |
| Dairy products | 8,025 | 1 (ref) | 0.93 (0.83, 1.04) | 0.84 (0.75, 0.95) | 0.004 |
| Butter, margarine | 7,583 | 1 (ref) | 0.95 (0.85, 1.07) | 0.82 (0.72, 0.92) | 0.0006 |
| Sweetened foods | 8,166 | 1 (ref) | 0.91 (0.82, 1.02) | 0.69 (0.61, 0.78) | <0.0001 |
| Alcoholic beverages | 7,680 | 1 (ref) | 0.89 (0.78, 1.01) | 0.88 (0.78, 0.99) | 0.03 |
| Non-alcoholic beverages | 8,174 | 1 (ref) | 0.93 (0.83, 1.03) | 0.67 (0.59, 0.76) | <0.0001 |
| Fast food | 7,934 | 1 (ref) | 0.94 (0.83, 1.08) | 0.87 (0.78, 0.97) | 0.01 |
| Extra food (including snacks, chips, salted biscuits, dressing and sauces) | 8,133 | 1 (ref) | 0.97 (0.86, 1.08) | 0.76 (0.67, 0.86) | <0.0001 |
| Other fats (including mayonnaise, fresh cream, vegetal fresh cream) | 7,613 | 1 (ref) | 1.10 (0.98, 1.24) | 0.89 (0.79, 1.00) | 0.05 |
| Dairy and meat substitutes (including soy-based products)[c] | 3,275 | N\A | 1 (ref) | 0.75 (0.62; 0.91) | N\A |
| Plant-based products (fruit and vegetables, starchy foods, whole-grain products, oil, dairy- and meat substitutes) | 8,174 | 1 (ref) | 0.96 (0.86, 1.07) | 0.76 (0.67, 0.86) | <0.0001 |

Abbreviations: MetS, Metabolic Syndrome; ref, reference.

[a] Values are prevalence ratios, PR (95%CI) for the relation between the proportion of organic food in the food group, as a categorical variable (tertiles) and Metabolic Syndrome modelled as a binary variable, adjusted for age, sex, educational level, monthly income, physical activity, smoking habits, season of blood sampling, time lag between organic food questionnaire completion and clinical visit, occupational status, location, energy intake, overall dietary quality (estimated by the mPNNS-GS as a continuous variable) and food group intake, among consumers of the food group.

[b] Number of consumers of the food group.

[c] Groups were defined using the median value as the number of non-consumers of the food group was particularly high.

**Table 4. Association between tertiles of proportion of organic food in the diet and metabolic traits, NutriNet-Santé study[a]**

| | N | Proportion of organic food in the whole diet (ratio) Tertile 1 | Tertile 2 | Tertile 3 | P for linear contrast |
|---|---|---|---|---|---|
| Fasting blood glucose (g/L) | | | | | |
| *Model 1* | 8,174 | 0.91 (0.91; 0.92) | 0.90 (0.90; 0.91) | 0.89 (0.89; 0.90) | <0.0001 |
| *Model 2* | 7,941 | 0.91 (0.90; 0.91) | 0.91 (0.90; 0.91) | 0.90 (0.90; 0.91) | 0.01 |
| Waist circumference (cm) | | | | | |
| *Model 1* | 8,174 | 84.91 (84.44; 85.37) | 83.23 (82.79; 83.68) | 80.88 (80.48; 81.29) | <0.0001 |
| *Model 2* | 8,174 | 86.57 (85.93; 87.21) | 85.99 (85.35; 86.64) | 84.1 (83.47; 84.73) | <0.0001 |
| SBP (mmHg) | | | | | |
| *Model 1* | 8,174 | 129.03 (128.40; 129.67) | 126.99 (126.36; 127.62) | 125.54 (124.93; 126.14) | <0.0001 |
| *Model 2* | 6,170 | 127 (126.1; 127.9) | 126.1 (125.2; 127.1) | 125.4 (124.4; 126.3) | 0.0002 |
| DBP (mmHg) | | | | | |
| *Model 1* | 8,174 | 76.89 (76.53; 77.25) | 75.97 (75.61; 76.32) | 75.68 (75.32; 76.04) | <0.0001 |
| *Model 2* | 6,170 | 77.16 (76.56; 77.78) | 76.45 (75.84; 77.07) | 76.10 (75.50; 76.72) | 0.0002 |
| Serum triglycerides (g/L) | | | | | |
| *Model 1* | 8,174 | 0.92 (0.90; 0.93) | 0.89 (0.88; 0.91) | 0.85 (0.83; 0.86) | <0.0001 |
| *Model 2* | 7,693 | 0.92 (0.89; 0.94) | 0.91 (0.89; 0.94) | 0.87 (0.85; 0.89) | <0.0001 |
| HDL-cholesterol (g/L) | | | | | |
| *Model 1* | 8,174 | 0.60 (0.60; 0.61) | 0.62 (0.61; 0.62) | 0.63 (0.62; 0.63) | <0.0001 |
| *Model 2* | 6,846 | 0.59 (0.59; 0.60) | 0.59 (0.59; 0.60) | 0.60 (0.59; 0.61) | 0.25 |

Abbreviations: BMI, Body Mass Index; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure; HDL, High Density Protein, LDL, Low Density Protein.

[a] Values are adjusted geometric means (95%CI) for the relation between the proportion of organic food as a categorical variable (tertiles) and metabolic traits. P-value referred to log-transformed variables.

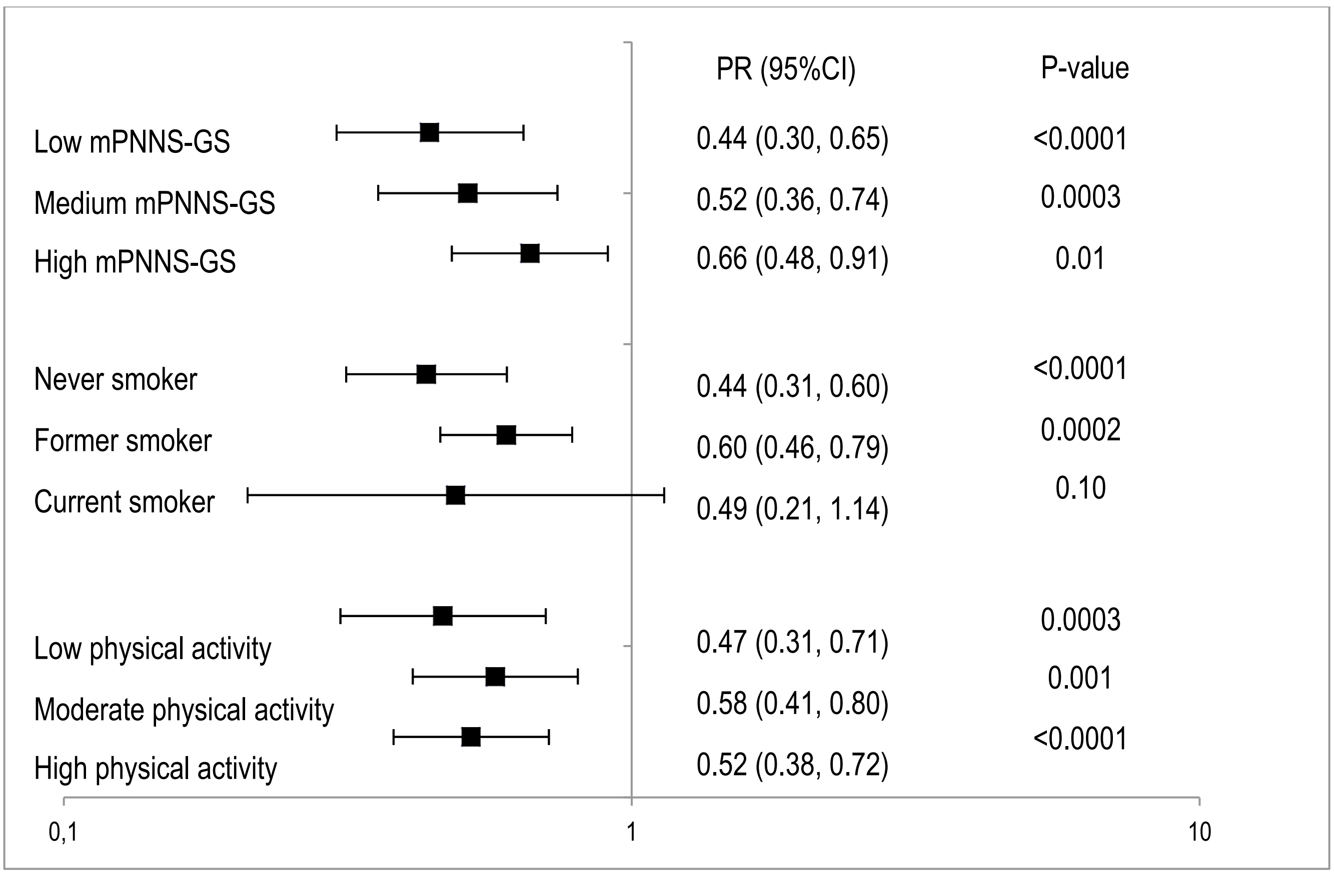
Model 1 is unadjusted. Model 2 is performed among sub-samples who are not taking any related medications for the specific outcome and is adjusted for age, sex, educational level, monthly income, physical activity, smoking habits, season of blood sampling, time lag between organic food questionnaire completion and clinical visit, occupational status, location, energy intake and overall dietary quality (estimated by the mPNNS-GS as a continuous variable).

**Figure 1. Association between the proportion of organic food in the diet (as a continuous variable) and MetS across subgroups, n=8,174, NutriNet-Santé study**

Abbreviations: CI, Confidence Interval; mPNNS-GS, modified Programme Nationale Nutrition Santé Guideline Score; PR, Prevalence Ratios.

[a] Model adjusted for age, sex, educational level, monthly income, season of blood sampling, time lag between organic food questionnaire completion and clinical visit, occupational status, location, energy intake and overall dietary quality (estimated by the mPNNS-GS as a continuous variable) and all other variables presented in the Figure.

**Figure 1. Association between the proportion of organic food in the diet (as a continuous variable) and MetS across subgroups, n=8,174, NutriNet-Santé study[a]**




Abbreviations: CI, Confidence Interval; mPNNS-GS, modified Programme Nationale Nutrition Santé Guideline Score; PR, Prevalence Ratios.

[a]Model adjusted for age, sex, educational level, monthly income, season of blood sampling, time lag between organic food questionnaire completion and clinical visit, occupational status, location, energy intake and overall dietary quality (reflected by the mPNNS-GS as a continuous variable) and all other variables presented in the Figure.