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1 **Prospective association between consumption frequency of organic food and body**
2 **weight change, risk of overweight or obesity: Results from the NutriNet-Santé Study**

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15 **Running title:** Organic food consumption and corpulence

16 **Keywords:** organic food, obesity, prospective cohort study, weight gain

Abbreviations: BMI: body mass index, OS: organic score, mPNNS-GS, PCA: Principal component analysis

17 Abstract

18 A lower body mass index (BMI) has been reported among consumers of organic foods but
19 this relationship has never been examined in a prospective design. Our aim was to
20 prospectively investigate the association between the frequency of organic foods and weight
21 change. We analyzed data from 62,224 participants of the NutriNet-Santé cohort (78%
22 women, mean age=45y) with information on consumption frequency of organic foods, dietary
23 intake, and repeated anthropometric data. For 16 products, participants reported their
24 consumption frequency of labeled organic foods (never, occasionally, most of the time). An
25 organic score (OS) with a maximum of 32 points was computed. The associations of the OS
26 (modeled as quartiles (Q)) with change in BMI during follow-up (on average 3·1 y), and with
27 the risk of overweight and obesity were estimated ANCOVA and multivariable logistic
28 regression. A lower BMI increase was observed across quartiles of the OS (mean difference
29 (95%CI) Q4 versus Q1= - 0·16 (-0·32, -0·01). An increase in OS was associated with a lower
30 risk of overweight and obesity (among non-overweight and non-obese participants at
31 inclusion): odds ratios (95%CI) Q4 versus Q1 were 0·77 (0·68, 0·86) and 0·69 (0·58, 0·82),
32 respectively. Concerning obesity risk, the association was stronger among participants with
33 higher adherence to nutritional guidelines. This study supports a strong protective role of
34 consumption frequency of organic foods concerning the risk of overweight and obesity that
35 depends on overall dietary quality. Upon confirmation, these results may contribute to fine-
36 tune nutritional guidelines by accounting for farming practices in food production.

37 **Introduction**

38 The global obesity epidemic, involving multifaceted origins, is a major public health issue ⁽¹⁾.

39 Overweight and obesity contribute to the global burden of chronic diseases ⁽²⁾ - especially

40 type 2 diabetes and ischemic cardiovascular diseases ⁽³⁾, along with cancers ^(4,5).

41 Among the factors involved in the etiology of obesity, excess caloric consumption, sedentary

42 lifestyle and genetic susceptibility are well-recognized, but there is a growing concern for the

43 identification of novel factors involved such as gut microbiota ⁽⁶⁾ or environmental chemicals

44 ⁽⁷⁻¹⁰⁾.

45 Among the different dietary factors, organic food is of major interest since it presents multiple

46 features that could potentially protect from weight gain and obesity. Notably, compared to

47 conventional food, organic food has been suggested to present better nutritional values

48 concerning fatty acids profiles and specific micronutrients ⁽¹¹⁻¹³⁾. Nonetheless, the possible

49 implications at an individual level in terms of daily nutrient intake are unknown due to the

50 lack of food composition tables accounting for farming practices. A small number of clinical

51 studies have been conducted that compared specific nutritional biomarkers according to the

52 type of diet (organic or conventional). However, due to short study durations, these studies

53 were not well-equipped to provide reliable results, and findings were inconsistent ⁽¹⁴⁾.

54 Organic foods are also characterized by a markedly low level or an absence of pesticide

55 residues, as repeatedly reported in food residue analyses ^(11,14,15) and in experimental studies

56 showing that adopting an organic diet leads to a drastic reduction in pesticide residues and

57 urine metabolites in children and adults ⁽¹⁶⁻²⁰⁾. For most pesticide families (organochlorines

58 (now banned in the EU but still persistent), organophosphates, and pyrethrynoïds), a large

59 number of molecules have been recognized as endocrine disruptors ⁽²¹⁾, leading to possible

60 metabolic disorders ⁽²²⁾. Indeed, a higher exposure to some of these compounds has been

61 associated with a higher risk for obesity or type 2 diabetes in humans ⁽⁹⁾.

62 In this context, consumption of organic foods might contribute to the management of weight
63 gain and of obesity risk. In a recent cross-sectional analysis based on the NutriNet-Santé
64 cohort, we showed that participants identified as regular consumers of organic food,
65 compared to non-consumers, presented reduced odds of being overweight or obese (-36% and
66 -62% in men and -42% and -48% in women, respectively) ⁽²³⁾. Comparable findings were
67 reported in the German National Nutrition Survey II (NVS II), a nationwide food
68 consumption study conducted among 13,074 adults: German buyers of organic food exhibited
69 healthier lifestyles compared with non-buyers, and presented lower body weight ⁽²⁴⁾.
70 To the best of our knowledge, no epidemiologic study has yet investigated the prospective
71 relation between consumption frequency of organic foods and the risk of overweight and
72 obesity. The main objective of the present study was thus to investigate the longitudinal
73 association between the frequency consumption of organic foods and change in body mass
74 index, the risk of overweight, and the risk of obesity in a very large adult cohort. Given our
75 previous finding that organic food consumers show a higher level of adherence to nutritional
76 recommendations ⁽²³⁾ - especially a higher consumption of fruit and vegetables and a lower
77 consumption of animal products - a secondary objective was to explore a potential modifying
78 effect of the nutritional quality of the diet on the investigated associations.

79 **Material and methods**

80 **Study population**

81 The NutriNet-Santé is a web-based prospective observational cohort that was launched in
82 France in May 2009. The objectives, design and methodology have been described elsewhere
83 ⁽²⁵⁾. The study was conducted according to the guidelines laid down in the Declaration of
84 Helsinki and was approved by the Institutional Review Board of the French Institute for
85 Health and Medical Research (IRB Inserm no. 0000388FWA00005831) and the “Commission

86 Nationale de l'Informatique et des Libertés” (CNIL no. 908450 and no. 909216). All subjects
87 signed an electronic informed consent.

88 **Data collection and computation**

89 Volunteers filled in self-administrated questionnaires using a dedicated website at baseline
90 and during follow-up on an approximately monthly basis. The baseline questionnaires,
91 inquired sociodemographic data and lifestyles, health status, physical activity,
92 anthropometrics and diet. These questionnaires were first pilot-tested and then compared to
93 traditional assessment methods or objectively validated ⁽²⁶⁻²⁸⁾.

94 *Consumption frequency of organic products data*

95 Two months after enrollment, volunteers were asked to provide information on their
96 consumption frequency of 16 labeled organic products (fruit, vegetables, soya, dairy products,
97 meat and fish, eggs, grains and legumes, bread and cereals, flour, vegetable oils and
98 condiments, ready-to-eat meals, coffee/tea/herbal tea, wine,
99 biscuits/chocolate/sugar/marmalade, other foods, dietary supplements). Initially, the
100 collection of these data was related to research questions focused on reasons for non-
101 consumptions. Consumption frequencies were presented in 8 modalities: (1) most of the time;
102 2) occasionally; 3) never (“too expensive”); 4) never (“product not available”); 5) never (“I’m
103 not interested in organic products”); 6) never (“I avoid such products”); 7) never (“for no
104 specific reason”); and 8) “I don’t know”). For each product, we allocated two and one points
105 to the “most of the time” and “occasionally” modalities, respectively (and 0 otherwise) - since
106 the objective of the present study was to focus on the level of frequency, and not on reasons
107 for non-consumption. The 16 dietary components were summed up to provide an **organic**
108 **score** (ranging from 0 to 32).

109 *Anthropometric data*

110 At enrollment and yearly after, participants were asked to report weight and height assessed
111 during a medical or occupational health examination by a physician, or from self-
112 measurement guided by standardized procedures (on flat surface, lightly dressed, and without
113 shoes). Self-reported anthropometric data have been shown to present an elevated
114 concordance with clinical assessment ⁽²⁶⁾.

115 Body mass index (kg/m²) was calculated as weight divided by the square of height. Subjects
116 were classified as underweight or normal weight (BMI<25), overweight (including obesity;
117 BMI≥25), or obese (BMI≥30) according to the World Health Organization (WHO) reference
118 values ⁽¹⁾.

119 *Dietary data and physical activity*

120 At baseline, quantitative dietary intakes were assessed using three 24-hour records (24HR),
121 randomly allocated over a two-week period, including two week-days and one weekend day,
122 using a validated method ^(27,28). Participants reported all foods and beverages consumed at
123 each eating occasion. Portion sizes were estimated with the help of photographs, derived from
124 a previously validated picture booklet ⁽²⁹⁾ or directly entered as grams, volumes or purchased
125 units. Since alcohol is only episodically consumed by most individuals, alcohol intake was
126 calculated using either the 24HR or a frequency questionnaire for those identified as
127 abstainers in the three 24HR days. Moreover, since fish and seafood are infrequently
128 consumed by many individuals, the weekly consumption of this food group was assessed by a
129 specific frequency question. . Individual daily mean food consumption was calculated from
130 the three 24HR, weighted for the type of day (week or weekend day). Nutrient intakes were
131 calculated using the NutriNet-Santé composition table ⁽³⁰⁾. Under-reporters were identified
132 and excluded using the validated method developed by Black ⁽³¹⁾. To assess nutritional diet
133 quality, a modified version of the validated PNNS-GS (without physical activity) was
134 computed. This modified score, the mPNNS-GS, reflects adherence to the official French

135 nutritional recommendations ⁽³²⁾. The score includes 12 components: eight refer to food-
136 serving recommendations (fruit and vegetables; starchy foods; whole grain products; dairy
137 products; meat, eggs and fish; fish and seafood; vegetable fat; water vs soda) and four refer to
138 moderation in consumption (added fat; salt; sweets; alcohol). Moreover, points are deducted
139 for overconsumption of salt, added sugars, or when energy intake exceeds the estimated
140 energy needs by more than 5%.

141 In order to also account for *a posteriori* dietary patterns, we performed a principal component
142 analysis (PCA), on 31 aggregated food groups. Dietary patterns obtained by PCA are
143 independent linear combinations of the 31 food group consumptions, maximizing the
144 explained variance. Two dietary patterns were retained based on Cattell's Scree plots and the
145 interpretability of the factors. **Supplementary table S1** presents all factor loading coefficients
146 (corresponding to the correlations between the different food groups and the two dietary
147 patterns) > 0.3. For each participant, the individual pattern score was calculated by summing
148 the intake of the 31 food groups, weighted by their factor loading.

149 *Covariates*

150 At baseline, self-administered questionnaires were used to collect data including age, gender,
151 formal education (\leq high school diploma, high school, post-secondary graduate), occupation
152 (managerial staff, intermediate profession, employee/manual worker, retired, unemployed,
153 never employed/homemaker and self-employed), marital status (cohabiting or single),
154 income, number of children and smoking status (never, former and current). Income per
155 household unit was calculated by dividing the household's total monthly income by the
156 number of consumption units (CU), using the following coefficients: 1 CU for the first adult
157 in the household, 0.5 CU for all other household members aged 14 or older and 0.3 CU for
158 children under 14 ⁽³³⁾. The following categories of monthly income were used: <1,200, 1,200-
159 1,800, 1,800-2,700 and >2,700 euros per household unit.

160 Physical activity was assessed by the International Physical Activity Questionnaire (IPAQ)
161 ⁽³⁴⁾. Metabolic equivalents (MET) measured in minutes per week were computed. The
162 recommended IPAQ categories of physical activity were used: low (<30 min of brisk
163 walking/day), moderate (30 - <60 min/day of brisk walking /day or equivalent) and high (\geq 60
164 min of brisk walking /day or equivalent).

165 The inquired baseline health data included use of medication and self-reported history of
166 diseases (cancer, cardiovascular diseases, hypertension, dyslipidemia and diabetes).

167 **Statistical analysis**

168 For the present study, we used data from volunteers who were included before June 2014 and
169 initially aged 18-74 y. Among them, we selected those 1) who completed the organic
170 questionnaire, 2) with baseline anthropometric data and at least one measurement during
171 follow-up, 3) with available data to compute PNNS-GS and 4) who were not identified as
172 energy underreporters (**Figure 1**). Follow-up anthropometric data were collected until June
173 2015.

174 The participants included (N=62,224) into our analyses were compared to those excluded,
175 using Mann-Whitney-U tests and Chi square tests.

176 Baseline characteristics were presented by quartiles of the organic score. Values represent
177 means (\pm SD) or percentages, and P-values were calculated using linear contrast tests (for
178 continuous variables) or Chi square trend tests (for categorical variables).

179 The association of the organic score with BMI change was assessed by covariance analysis
180 (ANCOVA), modeling change in BMI as a percentage of the baseline value. Mean differences
181 (95% confidence intervals) were presented across quartiles of the organic score. Three
182 different models were performed. The first model was adjusted for baseline age and gender.
183 The second model was further adjusted for year and month of inclusion, follow-up duration,
184 occupation, marital status, education, monthly income per household unit, baseline use of

185 dietary supplements, the mPNNS-GS, PCA-extracted dietary patterns scores, energy intake,
186 physical activity and smoking status. The final model was further adjusted for history of
187 diseases (cancer, cardiovascular diseases, diabetes, hypertension and dyslipidemia).
188 In a second set of analyses, we estimated odds ratios (OR) and 95% confidence intervals (CI)
189 for becoming overweight or obese after exclusion of overweight and obese subjects at
190 baseline, respectively (leading to new study samples of n= 43,301 and n=56,806). Three
191 multivariate logistic regression models were computed with similar covariables to those used
192 in the covariance analysis.

193 A set of supplementary analyses was performed for the obesity risk outcome. First, stratified
194 analyses were conducted according to physical activity level/day brisk walking versus ≥ 30
195 min/day brisk walking or equivalent), use of dietary supplements (yes versus no), tobacco
196 status (never and former smokers versus current smokers), education level, and level of
197 adherence to nutritional guidelines (using tertiles of the mPNNS-GS). Second, we used an
198 alternative method of accounting for potential confounder bias: adjustment for a ‘propensity
199 score’ that contains information on potential confounders in a combined manner⁽³⁵⁾. To
200 obtain the propensity score, a multinomial logistic regression model was used to estimate the
201 predicted probability of organic food consumption (using quartiles of the 16-point organic
202 score) as a function of a wide range of factors (sociodemographic, health characteristics, food
203 group consumptions). Finally, we used inverse probability weighting to correct the estimates
204 for potential selection bias⁽³⁶⁾. All tests of statistical significance were two-sided and the type
205 I error was set at 5%. Statistical analyses were performed using SAS® software (version 9.3,
206 SAS Institute Inc, Cary, NC, USA).

207 **Results**

208 *Comparison of included and excluded participants*

209 Compared with excluded subjects, included subjects (N=62,224) were older, had a higher
210 education level and income, were less often smokers and less physically active. They also
211 presented a lower BMI and a higher nutritional quality of the diet (all P-values<0.05, data not
212 tabulated).

213 *Baseline Characteristics of the sample*

214 Baseline characteristics across quartiles of organic score are shown in **Table 1**. Higher levels
215 of the organic score were related to higher proportions of women, participants who were
216 cohabiting, former smokers, physically active participants, individuals reaching a post-
217 secondary educational level, and participants with a high income or occupational level. A
218 positive association was also observed with age, follow-up duration and the mPNNs-GS
219 (reflecting the nutritional quality of the diet), while there was a negative association with
220 energy intake, alcohol consumption and BMI.

221 Components of the organic score across quartiles of the organic score are shown in **Table 2**.

222 In the first quartile (Q1), participants mostly reported no consumption of any organic
223 products. In the 4th quartile (Q4), participants reported more frequently consuming organic
224 products, especially products of the following food groups: eggs, starchy food, vegetables,
225 vegetable oil, fruits and flour.

226 Then mean follow-up time in our study sample was 3.12 (SD=1.37) years. Results on the
227 prospective association between the organic score and change in BMI over time are presented
228 in **Table 3**. In the second model, higher organic score levels were related to a substantially
229 lower increase in BMI over time (mean difference Q4 versus Q1= -0.15; confidence interval=
230 --0.31, -0.01, P for trend =0.05). After further adjustment for history of chronic diseases
231 (third model), an even stronger association was observed (mean difference Q4 versus Q1= -
232 0.16; confidence interval= -0.32, -0.01, P for trend =0.04).

233 Results on the prospective association between the organic score and the risk of overweight
234 and obesity are presented in **Table 4**. In the fully-adjusted model, accounting for
235 sociodemographic data, lifestyles and history of chronic diseases, a linear decrease in the risk
236 of overweight was observed across quartiles of the organic score, with risk reduction of 23%
237 in Q4 compared to Q1. Findings concerning the risk of obesity were similar, with a risk
238 reduction of 31% in Q4 compared to Q1.

239 Stratified analyses are presented in **Figure 2** and in **Supplemental Table S2**. We observed
240 that the association between the organic score and the risk of obesity was stronger among
241 participants with a higher nutritional quality of the diet. Overall, in the different stratified
242 analyses, the association between the organic score and the risk of obesity was observed in
243 each sub-group, except for dietary supplement users and participants with an intermediate
244 education level. Accounting for selection bias via inverse probability weighting did not
245 substantially modify our findings (data not shown). Models with additional adjustment for a
246 propensity score are presented in **Supplemental Table S3**. Here, the investigated associations
247 were attenuated but remained statistically significant.

248 **Discussion**

249 The present results show, for the first time, a strong negative association between the
250 consumption frequency of organic foods and BMI change over time, as well as a marked
251 reduction of the risk of overweight and obesity.

252 In stratified analyses, significant associations were observed in almost all investigated
253 subgroups, except for dietary supplement users and participants with an intermediate level of
254 education. Importantly, both participants with a low level of physical activity and participants
255 with a low education level presented a significantly lower risk of obesity with increasing
256 organic food consumption. It is noteworthy that the nutritional quality of the diet, estimated
257 by using an a priori dietary index reflecting adherence to the French nutritional guidelines⁽³²⁾,

258 appears to be a key effect modifier. Indeed, the strongest associations were observed among
259 participants presenting a high nutritional quality of the diet.

260 *Consumption frequency of organic foods and the risk of obesity or overweight*

261 We prospectively observed a markedly lower risk of obesity among subjects with a high
262 consumption frequency of organic foods. Previous investigations of data from the NutriNet-
263 Santé cohort have revealed that regular consumers of organic foods presented a healthier diet
264 and healthier lifestyle characteristics (related to physical activity and tobacco use) as
265 compared to irregular consumers or non-consumers. Moreover, regular consumers of organic
266 foods in the NutriNet-Santé study presented specificities with respect to chronic disease
267 history^(23,37). After accounting for these potential confounders, the findings of the present
268 study were partially attenuated but the association remained strong and highly significant,
269 with a reduction in the risk of obesity of 37% after a 3·1 y follow-up.

270 A similar association was observed for overweight, although the strength of the association
271 was smaller.

272 *Comparison of our results with the findings of other studies*

273 No previous longitudinal study has investigated the association between organic food
274 consumption frequency and weight change or the risk of overweight and obesity, but a
275 potential beneficial link between body weight and organic food consumption or purchase has
276 been documented in several cross-sectional studies^(23,24,38). For instance, a previous
277 investigation of NutriNet-Santé data⁽²³⁾ has shown that regular organic food consumers
278 showed a markedly lower probability of overweight (excluding obesity) and obesity
279 compared to non-consumers (-36% and -62% in men and -42% and -48% in women,
280 respectively). In addition, in the German National Nutrition Survey II⁽²⁴⁾, as compared to
281 non-buyers of organic food, buyers of organic food presented lower proportions of
282 overweight (35·5% versus 39·2%) and obesity (17·9% versus 22·5%). Our findings are also

283 concordant with a small Italian clinical study (including 100 healthy males and 50 males
284 suffering from chronic kidney disease, CDK) that reported a statistically significant reduction
285 in weight among CDK patients after introducing an organic diet for a 2-week period
286 (85.17 ± 13.97 kg at baseline versus 79.52 ± 10.41 kg after the 2-week intervention, $p < 0.05$)⁽³⁹⁾.
287 Overall, the currently available cross-sectional or longitudinal surveys consistently reported
288 an association between higher organic food consumption and a lower BMI. The association
289 with a lower increase in BMI over time that we observed in the present study is of particular
290 interest as it supports a possible role of the organic-based diet in weight management among
291 all subjects, beyond the risk of overweight or obesity among initially normal weight (or
292 underweight) individuals.

293 *Modulating effect of the nutritional quality of the diet*

294 There is growing evidence supporting the observation that consumers of organic food present
295 a nutritionally healthier diet as well as other beneficial lifestyles such as lower alcohol
296 consumption, no smoking and a higher physical activity level^(23,24,40,41). Thus, we
297 hypothesized that the link between consumption of organic foods and body weight might be
298 modulated by the overall nutritional quality of the diet. Indeed, we found that the strongest
299 reduction in obesity risk (related to a higher consumption frequency of organic foods) was
300 observed among participants with a healthier diet. Conversely, among participants with a less
301 healthy diet (susceptible to promote weight gain), the association between consumption
302 frequency of organic food and obesity risk was of smaller magnitude. It is well known that
303 unhealthy eating habits play a key role in the etiology of obesity⁽³⁾. Therefore, the mode of
304 production of the foods consumed may be of secondary importance in these subjects. It is also
305 possible that their dietary patterns, which are low in fruit and vegetables, lead to less
306 contaminated diets.

307 Several hypotheses can be proposed to explain the differences in the risk of obesity between
308 organic food consumers and non-consumers who present a healthy diet. Because we adjusted
309 and then stratified for the global nutritional quality of the diet (using the mPNNS-GS score) in
310 our models, it is not probable that our results were biased by the fact that organic food
311 consumers present healthier diets. Other possible explanations include differences in organic
312 food and conventional food with respect to various nutritional compounds.

313 First, the results of a number of studies argue for a higher concentration of polyunsaturated
314 fatty acids (especially n-3 fatty acids) in organic dairy and meat products; and of antioxidants
315 (especially vitamin C and phenolic compounds) in organic plant foods⁽¹¹⁻¹³⁾. While observed
316 differences in nutrient content can vary by about 10-68% at the food level (not accounted for
317 in our study), it is possible that the overall variations of nutrient intake in an organic diet is
318 sufficient to affect weight management^(42,43). However, this remains to be further evaluated.

319 Another hypothesis is related to the fact that individuals with a higher adherence to the French
320 nutritional guidelines tend to consume more plant-based foods. It is well known that plant
321 foods are frequently contaminated by various pesticide residues (about 45% of the tested
322 samples in Europe)⁽⁴⁴⁾ because they are heavily sprayed with pesticides during conventional
323 agricultural production and storage. This hypothesis is in line with findings of human surveys
324 that have related obesity and type 2 diabetes to pesticide exposure^(7,9,10,45,46). Thus, unlike the
325 consumption of pesticide-free or only slightly contaminated plant products^(11,14,15), a high
326 consumption of conventionally grown plant foods may be related to adverse health effects
327 related to higher pesticide exposure.

328 Indeed, replacing conventional food by organic food has repeatedly been shown to drastically
329 reduce the level of organophosphate residues in human urines⁽¹⁶⁻²⁰⁾. A specific example of a
330 potential adverse health effect of contaminated fruit and vegetables is that high consumers of
331 conventional or contaminated fruits and vegetables presented a particularly low semen quality

332 ^(47,48). This reinforces the concept that different dietary profiles (with various degrees of intake
333 of contaminated food) lead to different levels of exposure to “obesogen” chemicals ⁽⁹⁾, but this
334 hypothesis needs to be investigated in future biomonitoring-based studies that compare
335 organic and conventional diets with various dietary profiles.

336 *Potential mechanistic pathways explaining the association between organic food consumption*
337 *and body weight*

338 Our findings may be interpreted in light of the reduced exposure to pesticides among organic
339 food consumers. Pesticides (prohibited in organic farming when they are synthetic) often
340 present endocrine-disrupting properties that cause developmental and reproductive
341 abnormalities via the modification of signaling processes ⁽⁴⁶⁾. Besides, new scientific research
342 argues for a role of pesticides in metabolic disruption, ⁽²²⁾ leading to obesity and type 2
343 diabetes ⁽⁹⁾. Mechanistic pathways depend on the type of pesticides. Previous studies have
344 shown an alteration of glucose and lipid metabolism by organochlorines ⁽⁴⁹⁾. Moreover,
345 organochlorines have been shown to affect the control of adipogenesis through an alteration
346 of glucose transport and glycolysis, an alteration of mitochondrial activity, and of fatty acid
347 oxidation ⁽⁴⁹⁾. Organophosphates have been shown to alter carbohydrate and lipid metabolism
348 by disrupting glucose homeostasis ⁽⁴⁹⁾. In addition, some pesticides have been shown to affect
349 the regulation of eating behavior and the differentiation of adipocytes ⁽⁵⁰⁾.

350 Further studies are necessary to better evaluate metabolic disruption and the “obesogen”
351 capacity of endocrine-disrupting chemicals contained in conventional foods.

352 *Strengths and limitations*

353 The main limitation of our study is that it is based on self-reported weight and height data.
354 However, these data have been shown to have a good concordance with data from clinical
355 assessments in a validation study ⁽²⁶⁾. This validation study showed high intraclass correlation
356 coefficients, ranging from 0.94 for height to 0.99 for weight, and the concordance for BMI

357 classification was 93% (sensitivity=88% and specificity=99%). Second, the generalizability
358 of our findings is limited since participants were volunteers involved in a long-term cohort
359 focused on nutrition and health. The individuals included in our study sample are thus likely
360 to be particularly health conscious. A final limitation pertains to the difficulty to disentangle
361 the role of overall dietary patterns from the role of organic food consumption, despite of the
362 extensive adjustment and stratification made. Since the design of our study is observational,
363 residual confounding cannot be ruled out. In particular, it is likely that unmeasured or only
364 indirectly measured factors, including genetic factors, ethnicity, environmental (e.g. food or
365 built environment) or psychological factors (e.g. occupational stress) may modify the
366 association between organic food consumption and obesity.

367 Our study also presents important strengths. First, the rich and accurately collected data
368 permitted to account for a broad range of potential confounders, including lifestyles and
369 health outcomes. Moreover, the very large sample size of our study enabled us to conduct
370 statistically powerful stratified analyses. Another important strength is the prospective design
371 of our analysis that implies a high level of evidence. Finally, the availability of accurate
372 dietary data allowed us to adjust for the nutritional quality of the diet, using a validated
373 dietary index.

374 **Conclusion**

375 This study, based on data collected in a very large prospective cohort, is the first to support a
376 prospective relation between consumption frequency of organic foods and body weight
377 change, as well as a strong negative association with the risk of overweight and obesity. The
378 overall nutritional quality of the diet may exert a modulating effect in these relationships, with
379 a stronger effect observed among those presenting a healthy plant-based diet. Further studies,
380 especially studies based on quantitative organic consumption data taking into account a
381 diversity of dietary profiles (plant based, western etc.), are needed to confirm these results. If

382 confirmed, these findings are of major interest from a public health point of view, as they
383 reinforce the need to fine-tune nutritional guidelines by accounting for the mode of food
384 production.

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396 **Conflict of Interest**

397 None of the authors declares any conflict of interest.

398 **Authorship**

399 EKG: conducted the literature review and drafted the manuscript; EKG: performed analyses;
400 EKG, JB, KEA, PG, SH and DL: were involved in the interpretation of results and critically
401 reviewed the manuscript; and SH, PG and EKG: were responsible for the development of the
402 design and the protocol of the study. All authors read and approved the final manuscript.

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527

533 **Table 2 Components of the organic score, across organic score quartiles, Nutrinet-Santé**
 534 **study, N=62,224***

	Q1	Q2	Q3	Q4	P [†]
Fruits	0·06 (0·25)	0·57 (0·52)	0·95 (0·41)	1·49 (0·53)	<0·0001
Vegetables	0·07 (0·27)	0·59 (0·55)	0·97 (0·48)	1·51 (0·54)	<0·0001
Rice, pasta, other cereals	0·06 (0·23)	0·42 (0·51)	0·90 (0·50)	1·62 (0·52)	<0·0001
Breads	0·05 (0·22)	0·36 (0·51)	0·82 (0·53)	1·44 (0·59)	<0·0001
Flour	0·04 (0·20)	0·23 (0·45)	0·67 (0·62)	1·47 (0·65)	<0·0001
Vegetable oils	0·04 (0·22)	0·27 (0·51)	0·74 (0·65)	1·58 (0·58)	<0·0001
Dairy products	0·05 (0·23)	0·40 (0·54)	0·86 (0·58)	1·42 (0·65)	<0·0001
Meats & seafoods	0·02 (0·14)	0·19 (0·41)	0·50 (0·54)	0·92 (0·66)	<0·0001
Eggs	0·13 (0·36)	0·70 (0·70)	1·19 (0·70)	1·72 (0·54)	<0·0001
Soja products	0·06 (0·24)	0·20 (0·44)	0·40 (0·59)	0·88 (0·76)	<0·0001
Sweet products	0·03 (0·19)	0·33 (0·48)	0·76 (0·50)	1·38 (0·58)	<0·0001
Tea, coffee, herbal tea	0·04 (0·19)	0·27 (0·47)	0·66 (0·59)	1·33 (0·67)	<0·0001
Wines	0·03 (0·17)	0·14 (0·35)	0·29 (0·47)	0·65 (0·64)	<0·0001
Ready-to-use dishes	0·01 (0·08)	0·06 (0·24)	0·19 (0·39)	0·39 (0·54)	<0·0001
Dietary supplements	0·03 (0·18)	0·13 (0·36)	0·25 (0·49)	0·56 (0·68)	<0·0001
Other dietary items	0·01 (0·12)	0·09 (0·30)	0·24 (0·45)	0·80 (0·80)	<0·0001

535 Q ; Quartile

536 *Values are means (SD) of sub-score given that non-consumption, occasional, regular
 537 consumption are coded 0, 1, 2, respectively.

538 †P for linear trend

539 **Table 3 Association between organic score in quartile and BMI change over time,**
 540 **Nutrinet-Santé study, 2009-2015, N=62,224***

model	Q1	Q2	Q3	Q4	P for trend
Model 1 [†]	0·00 (ref)	0·01 (-0·13, 0·15)	-0·06 (-0·20, 0·08)	-0·34 (-0·49, -0·20)	<0·0001
Model 2 [‡]	0·00 (ref)	0·03 (-0·11, 0·17)	0·01 (-0·13, 0·16)	-0·15 (-0·31, -0·00)	0·05
Model 3 [§]	0·00 (ref)	0·03 (-0·12, 0·17)	0·01 (-0·14, 0·15)	-0·16 (-0·32, -0·01)	0·04

541 **Q; Quartile**

542 *Values are mean differences (95% confident intervals). A negative value (-0·xx) indicates
 543 that the observed increase (expressed as a percentage of the initial anthropometric marker)
 544 was lower of 0·xx in the respective quartile than in quartile 1 (ref).

545 [†]Model 1 is adjusted for age and gender.

546 [‡]Model 2 is model 1 further adjusted for month and year of inclusion, duration of follow-up,
 547 occupation, marital status, education, monthly income per unit, dietary supplement use,
 548 mPNNS-GS, PCA-extracted dietary patterns scores, energy intake, physical activity and
 549 tobacco status.

550 [§]Model 3 is model 2 further adjusted for the history of chronic diseases.

551 **Table 4 Prospective association between quartiles of the organic score and overweight or**
 552 **obesity risk, Nutrinet-Santé study, 2009-2015*.**

	Model	Q1	Q2	Q3	Q4	P for trend
Overweight (N=3,259/40,042)						
	Model 1 [†]	1.00	0.94 (0.86- 1.04)	0.83 (0.75- 0.91)	0.62 (0.56- 0.69)	<.0001
	Model 2 [‡]	1.00	1.00 (0.91, 1.10)	0.93 (0.84, 1.02)	0.75 (0.67, 0.84)	<.0001
	Model 3 [§]	1.00	1.00 (0.91, 1.10)	0.93 (0.84, 1.03)	0.77 (0.68, 0.86)	<.0001
Obesity (1,337/55,469)						
	Model 1 [†]	1.00	0.87 (0.75, 1.01)	0.79 (0.68, 0.91)	0.52 (0.45, 0.61)	<.0001
	Model 2 [‡]	1.00	0.93 (0.80, 1.08)	0.90 (0.78, 1.04)	0.66 (0.55, 0.78)	<.0001
	Model 3 [§]	1.00	0.94 (0.81, 1.09)	0.92 (0.79, 1.06)	0.69 (0.58, 0.82)	0.0001

553 *Overweight (including obesity) and obesity analyses were performed among participants who
 554 were not overweight or obese at inclusion, respectively. Values are odds ratios (95% confident
 555 intervals), using 1st quartile Q1 as the reference.

556 [†]Model 1 is adjusted for age and gender.

557 [‡]Model 2 is model 1 further adjusted for month and year of inclusion, delay of follow-up,
 558 occupation, marital status, education, monthly income per unit, dietary supplement use,
 559 mPNNS-GS, PCA-extracted dietary patterns scores, energy intake physical activity and
 560 tobacco status.

561 [§]Model 3 is model 2 further adjusted for the history of chronic diseases.

562 **Supplemental Table S1: Factor loading matrix, NutriNet-Santé study***

Variable	Factor1	Factor2
Vegetables	0·65	0·14
Fruit	0·45	0·06
Broth	0·43	0·17
Coffee, tea, tisane	0·43	0·01
Soda	-0·42	0·06
Croissants	-0·37	0·03
Nuts	0·36	0·04
Fat and sweet products	-0·35	0·07
Dried fruits	0·33	-0·03
Snacks	-0·28	0·23
Soya products	0·28	-0·16
Meat and meat products	-0·28	0·39
Seafood	0·27	-0·02
Dairy desserts	-0·25	0·04
Bread and breakfast cereals	0·22	0·54
Cakes and pastries	-0·18	0·15
Alcoholic beverages	-0·18	0·34
Margarine	0·16	0·12
Flour	0·13	0·06
Eggs	0·12	0·02
Animal Fat	0·09	0·41
Dairy products	0·07	-0·09
Cheese	-0·05	0·53
Potatoes	0·05	0·41
Vegetable oils	0·03	0·28
Starchy food	0·03	0·07
Meal substitutes	0·02	-0·16
Sauces	-0·01	0·23
Sweet products	-0·01	0·27
Water and non-sweet bevarages	0·01	0·14
Wine	0·01	0·42

563 *Absolute values < 0·3 are not displayed in the table.

564 **Supplemental Table S2 Prospective association between quartiles of the organic score**
 565 **and obesity risk, stratified analyses, Nutrinet-Santé study, 2009-2015^{†,†}.**

	Q1	Q2	Q3	Q4	P for trend
Education					
< high school diploma	1·00	1·21 (0·91, 1·61)	0·88 (0·65, 1·19)	0·73 (0·52, 1·04)	0·04
High school diploma	1·00	0·80 (0·56, 1·14)	0·97 (0·69, 1·35)	0·82 (0·55, 1·20)	0·48
Post-secondary graduate	1·00	0·95 (0·78, 1·15)	0·92 (0·75, 1·12)	0·69 (0·55, 0·87)	0·003
Physical activity					
<30 min/day brisk walking	1·00	0·68 (0·51, 0·90)	0·76 (0·58, 1·01)	0·53 (0·38, 0·74)	0·001
≥30 min/day brisk walking or equivalent	1·00	0·97 (0·80, 1·18)	0·90 (0·73, 1·10)	0·74 (0·59, 0·92)	0·01
Smoking status					
Never or former smokers	1·00	0·95 (0·81, 1·11)	0·90 (0·76, 1·06)	0·72 (0·59, 0·86)	0·001
Current smokers	1·00	0·74 (0·51, 1·06)	0·95 (0·65, 1·38)	0·55 (0·36, 0·86)	0·04
Dietary supplement users					
yes	1·00	1·16 (0·94, 1·45)	1·05 (0·84, 1·32)	0·79 (0·61, 1·03)	0·11
no	1·00	0·92 (0·75, 1·12)	0·75 (0·60, 0·95)	0·67 (0·52, 0·85)	0·0003

566 [†]Obesity analyses were performed among participants who were not obese at inclusion
 567 (N=56,806). Values are odds ratios (95% confident intervals), using 1st quartile Q1 as the
 568 reference.

569 ^{††}Models are adjusted for age, gender, month and year of inclusion, delay of follow-up,
 570 occupation, marital status, education, monthly income per unit, dietary supplement use,
 571 mPNNs-GS, PCA-extracted dietary patterns scores, energy intake physical activity, tobacco
 572 status and for the history of chronic diseases.

573 **Supplemental Table S3 Prospective association between quartiles of the organic score**
 574 **and obesity risk, sensitive analysis, Nutrinet-Santé study, 2009-2015***

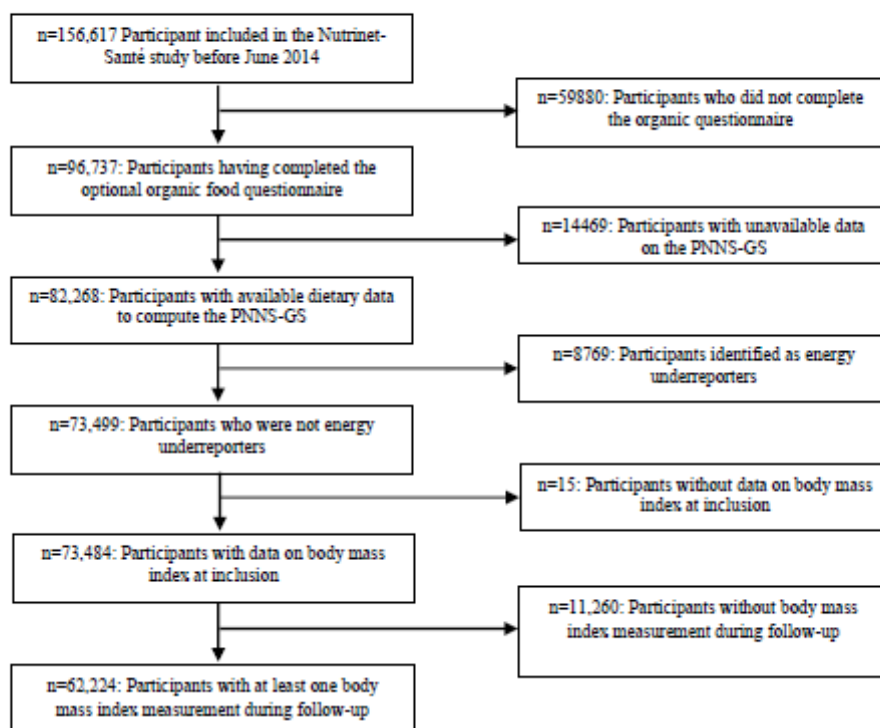
Model	Q1	Q2	Q3	Q4	P for trend
Model 1 [†]	1·00	0·87 (0·81, 0·94)	0·79 (0·73, 0·85)	0·52 (0·48, 0·57)	<·0001
Model 2 [‡]	1·00	0·93 (0·87, 1·01)	0·91 (0·84, 0·98)	0·67 (0·61, 0·72)	<·0001
Model 3 [§]	1·00	0·95 (0·88, 1·02)	0·92 (0·86, 0·99)	0·70 (0·64, 0·76)	<·0001

575 *Obesity analyses were performed among participants who were not obese at inclusion
 576 (N=56,806). Values are odds ratios (95% confident intervals), using 1st quartile Q1 as the
 577 reference.

578 [†]Model 1 is adjusted for age and gender and propensity score.

579 [‡]Model 2 is model 1 further adjusted for month and year of inclusion, delay of follow-up,
 580 occupation, marital status, education, monthly income per unit, dietary supplement use,
 581 mPNNS-GS, PCA-extracted dietary patterns scores, energy intake physical activity and
 582 tobacco status.

583 [§]Model 3 is model 2 further adjusted for the history of chronic diseases.

584 **Figure 1. Participants of the NutriNet-Santé selected for the present analyses, 2009–2015**

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586

587 **Figure 2. Prospective association between organic score in quartile and risk of obesity**
 588 **stratified according the nutritional quality of the diet, Nutrinet-Santé, 2009-2015***

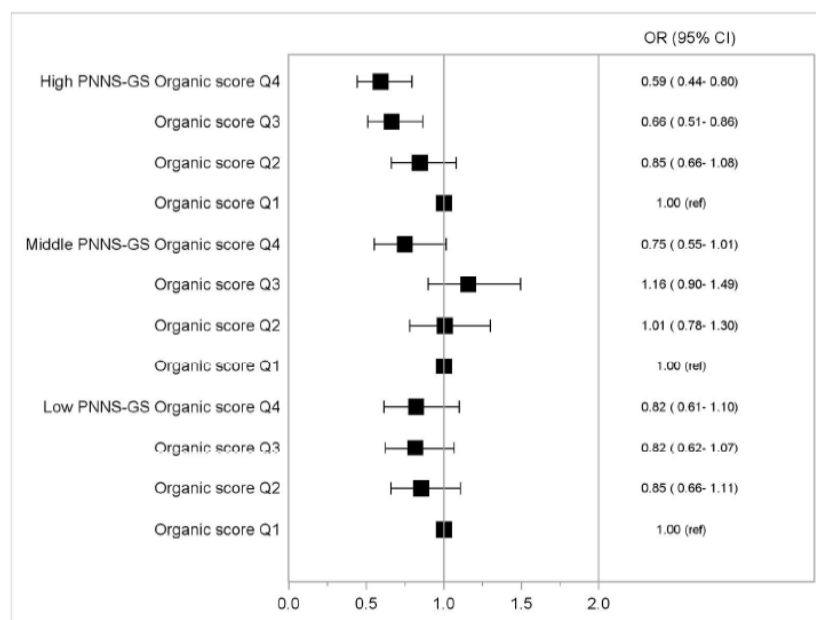


Figure 2. Prospective association between organic score in quartile and risk of obesity stratified according the nutritional quality of the diet, Nutrinet-Santé, 2009-2015*

*Values are odds ratios (95% confident intervals) using the 1st quartile (Q1) as the reference, adjusted for age, gender, month and year of inclusion, delay of follow-up, occupation, marital status, education, monthly income per unit, dietary supplement use, mPNNS-GS, PCA-extracted dietary patterns scores energy intake, physical activity, tobacco status and history of chronic diseases.

589

590 *Values are odds ratios (95% confident intervals) using the 1st quartile (Q1) as the reference, adjusted for age,
 591 gender, month and year of inclusion, delay of follow-up, occupation, marital status, education, monthly income
 592 per unit, dietary supplement use, mPNNS-GS, PCA-extracted dietary patterns scores energy intake, physical
 593 activity, tobacco status and history of chronic diseases.

528 **Table 1 Baseline characteristics of the sample across organic score quartiles, Nutrinet-Santé study, 2009-2014, N=62,224***

	Q1	Q2	Q3	Q4	P†
N	15,245	16,249	15,807	14,923	
Organic score max=32	0.73 (0.82)	4.96 (1.41)	10.36 (1.68)	19.15 (4.21)	<0.0001
Female (%)	73.45	77.94	78.71	81.63	<0.0001
Age (years)	44.16 (15.34)	44.36 (14.83)	45.62 (14.29)	46.72 (13.29)	<0.0001
Follow-up duration (days)	1140.34 (504.64)	1157.01 (500.06)	1144.88 (501.80)	1118.12 (499.69)	<0.0001
Education (%)					<0.0001
Unidentified	0.68	0.66	0.58	0.82	
< high school diploma	23.68	20.09	17.21	15.22	
High school diploma	19.12	17.01	15.44	13.99	
Post-secondary graduate	56.52	62.24	66.76	69.97	
Monthly income per unit household unit in € (%)					<0.0001
Missing	12.06	11.50	10.62	9.35	
900-1200	19.48	16.13	13.26	12.36	
1200-1800	26.76	25.15	22.67	23.09	
1800-2700	21.66	23.72	24.89	26.20	
>2700	20.05	23.50	28.56	29.00	

Occupational categories (%)					<0.0001
Non employed	5.60	5.35	5.18	5.84	
Retired	21.66	20.35	21.40	20.31	
Employee/Manual worker	23.22	19.82	16.67	14.29	
Intermediate profession	16.20	17.44	17.42	18.53	
Managerial staff	17.82	21.47	25.48	28.26	
Never employed	13.93	13.92	12.17	10.43	
Craftsman, shopkeeper, business owner, farmer	1.58	1.66	1.68	2.34	
Dietary supplement use (%)	35.52	45.55	51.58	62.13	<0.0001
Cohabiting (%)	80.89	81.88	83.22	86.32	<0.0001
Tobacco status (%)					<0.0001
Former smoker	33.05	33.09	35.51	37.69	
Current smoker	15.29	15.31	14.46	13.12	
Never smoker	51.66	51.60	50.03	49.19	
Physical activity (%)					<0.0001
Missing	15.12	14.36	12.85	11.96	
Low	15.12	14.36	12.85	11.96	
Medium	27.65	27.92	30.04	31.9	

High	33·67	37·15	38·33	39·5	
Energy intake (kcal/d)	1942·90 (514·75)	1914·76 (487·92)	1908·50 (491·42)	1894·24 (474·50)	<0·0001
% Carbohydrates	42·59 (6·89)	42·93 (6·81)	43·05 (6·94)	43·43 (7·11)	<0·0001
% Lipids	39·22 (6·61)	38·95 (6·46)	38·96 (6·58)	39·45 (6·72)	0·0017
% Proteins	17·87 (3·95)	17·80 (3·92)	17·67 (4·01)	16·81 (3·92)	<0·0001
Alcohol consumption (g/d)	8·65 (14·11)	8·27 (13·16)	8·22 (12·23)	7·63 (11·20)	<0·0001
mPNNS-GS	7·60 (1·62)	7·87 (1·62)	8·15 (1·60)	8·44 (1·58)	<0·0001
Body mass index (kg/m ²) at baseline	24·50 (4·87)	23·96 (4·56)	23·71 (4·31)	23·00 (3·90)	<0·0001
Obesity [‡] (%) at baseline	11·79	9·42	7·96	5·58	<0·0001
Body mass index (kg/m ²) at follow-up	24·72 (4·92)	24·17 (4·62)	23·91 (4·40)	23·13 (4·00)	<0·0001
Obesity [‡] (%) at follow-up	12·62	10·04	8·78	6·06	<0·0001

529 Abbreviations: Q; Quartile

530 *All variables were assessed at baseline, except when listed as “at follow-up”

531 †P for linear contrast

532 ‡Body mass index ≥ 30 kg/m²