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Sustainability analysis of the Mediterranean diet: results from the French NutriNet-Santé study.

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Abstract

The Mediterranean diet is often proposed as a sustainable diet model. This study aimed to evaluate the associations between adherence to the Mediterranean diet and sustainability domains in a cohort of French adults, using multiple criteria including nutritional quality, environmental pressures, monetary cost, and dietary pesticide exposure. Food intakes of 29,210 NutriNet-Santé volunteers were assessed in 2014 using a semi-quantitative food frequency questionnaire. Adherence to the Mediterranean diet was evaluated using the validated literature-based adherence score (MEDI-LITE). The associations between the MEDI-LITE and various sustainability indicators were examined using analysis of covariance models, adjusted for sex, age and energy intake. Higher adherence to the MEDI-LITE was associated with higher nutritional quality scores, better overall nutrient profile as well as reduced environmental impact (land occupation: Q5 vs. Q1: -35%, greenhouse gas emissions: -15%, and cumulative energy demand: -17%). In turn, monetary cost increased with increasing adherence to the Mediterranean diet (Q5 vs. Q1: +15%) while higher adherents to the Mediterranean diet had overall higher pesticide exposure due to their high plant-based food consumption. In this large cohort of French adults, greater adherence to the Mediterranean diet was associated with nutritional and environmental benefits, but also with higher monetary cost and greater exposure to pesticides, illustrating the necessity to develop large-scale strategies for healthy, safe (pesticide- and contaminant-free), and environmentally sustainable diets for all.

1 **Introduction**

2 Our current food system is not sustainable and will not enable us to achieve the objectives
3 defined by different international organisations, including the Paris agreement targets (1,2).
4 First, Western diets, characterised by calorie-dense foods, high intakes of red and processed
5 meat, processed food, salt and sugar and reduced intakes of complex carbohydrates, fibre,
6 fruits and vegetables, are major risk factors for morbidity and mortality worldwide (2).
7 Second, current food systems account for 20 to 30% of total greenhouse gas emissions
8 (GHGE) (3), 50% of land use (4). Dominant practices of food production also contribute to
9 biodiversity loss and degradation of natural resources (5). Third, emerging studies conducted
10 in the general population suggest potential adverse health effects of pesticide residues
11 contained in food (6–8). Finally, many people do not have access to, or cannot afford, a
12 healthy and sustainable diet (1,9). These trends will likely worsen in a context of a growing
13 world population, while many planetary boundaries have been already crossed, threatening
14 planetary habitability (10).

15 In 2010, sustainable diets have been defined by the United Nations Food and Agriculture
16 Organisation (FAO) as diets that bring nutritious and safe food for all, are economically
17 equitable and affordable, do not jeopardize natural resources, and ensure food security for
18 current and future generations (11).

19 The Mediterranean dietary pattern, which is characterised by a high consumption of fruits,
20 vegetables, wholegrain cereals, legumes, nuts, olive and olive oil, a moderate consumption of
21 fish and poultry, and a low consumption of meat (12), is often promoted as a healthy and
22 environmentally sustainable diet that is socioculturally acceptable and has positive local
23 economic benefits (13). The traditional Mediterranean “lifestyle” expands the concept to other
24 components, such as adequate rest, physical activity, frugality, dietary diversity, or personal
25 involvement (i.e. conviviality including culinary preparation with others and shared meals)
26 (14). It is also recommended to favour local, seasonal, ecological and minimally processed
27 foods that promote biodiversity (15).

28 The health benefits of the Mediterranean diet have been extensively studied, and studies
29 showing inverse associations between adherence to a Mediterranean diet and non-
30 communicable diseases, such as type 2 diabetes or metabolic syndrome, but also certain types
31 of cancers, are numerous (16). In addition, a large trial demonstrated that a Mediterranean diet
32 supplemented with extra-virgin olive oil or tree nuts reduces the incidence of major

33 cardiovascular events compared to individuals following a reduced-fat diet among high
34 cardiovascular risk individuals (17).

35 While a large body of evidence has highlighted the health benefits of adherence to
36 Mediterranean dietary patterns (18), fewer studies have examined the environmental impact
37 of these diets. In general, they tended to suggest that Mediterranean diets may have lower
38 environmental impacts than Western diets (19,20). Furthermore, according to a recent meta-
39 analysis, the Mediterranean diet does not appear more expensive than other diets (20),
40 although some studies have yielded divergent results (21,22).

41 In addition, few studies have evaluated other diet sustainability features (21), in particular
42 safety aspects (such as pesticide exposure), using quantitative data (23). It is, however, of
43 great importance to evaluate the sustainability of the Mediterranean diet in all its complexity
44 to gain a more complete understanding of its potential as a sustainable diet (24,25).

45 In that context, the primary goal of this study was to examine the relationship between
46 adherence to the Mediterranean diet and various sustainability features (nutritional quality,
47 environmental pressures, monetary cost, dietary pesticide exposure), in line with the FAO
48 definition of sustainable diets, in a large cohort of French adults. We also investigated
49 whether higher adherence to the Mediterranean diet was related to some other Mediterranean
50 lifestyle principles.

51

52 **Methods and Data**

53 **Study population**

54 The NutriNet-Santé study is a prospective observational cohort of French adult volunteers
55 launched in May 2009 and based on the internet (26). Upon inclusion in the cohort,
56 participants completed a set of self-administered questionnaires about dietary intake, health,
57 socio-economic status, physical activity, anthropometric and lifestyle characteristics. As part
58 of the follow-up, volunteers are regularly invited to update their sociodemographic, lifestyle,
59 dietary and health data and also to fill in optional questionnaires regarding dietary behaviours.

60 This study was conducted according to guidelines laid down in the Declaration of Helsinki.
61 All procedures were approved by the Institutional Review Board of the Institut National de la
62 Santé et de la Recherche Médicale (IRB INSERM no. 0000388FWA00005831) and the
63 Commission Nationale de l'Informatique et des Libertés (CNIL no. 908450 and no. 909216).
64 It is registered at ClinicalTrials.gov with the number NCT03335644. Electronic informed
65 consent was signed by all participants at inclusion.

66

67

68 **Dietary intake assessment**

69 Food intake was assessed using a semi-quantitative food frequency questionnaire (called Org-
70 FFQ) administered from June to December 2014. The Org-FFQ was built upon a pre-existing
71 validated food frequency questionnaire (27) to which statements regarding organic food
72 consumption were added. In brief, participants had to detail their consumption of 264 items
73 over the preceding year in order to estimate their total food intake. More specifically, they had
74 to complete the frequency and the portion size or quantity of each food item (28). In addition
75 to providing the latter, participants were also asked to report the consumption frequency in
76 their organic form of each food item, by ticking one of the following frequency modalities:
77 never, rarely, half-of-time, often or always. To obtain organic food consumption, a weight of
78 0, 0.25, 0.5, 0.75 and 1 was applied to the respective frequencies. More detailed information
79 about the Org-FFQ and sensitivity analyses regarding the weighting were published elsewhere
80 (29). Nutrient values were derived from a published food composition database (30).

81

82 **Mediterranean diet scores**

83 Two scores were used in order to evaluate the adherence to the Mediterranean diet
84 (**Supplemental Table 1**): the validated Literature-based adherence score to the Mediterranean
85 diet (MEDI-LITE) (31,32), as the primary exposure, and the historical Mediterranean diet
86 Score (MDS) (12). The MEDI-LITE is composed of six beneficial components that are
87 typical of the Mediterranean diet (fruits, vegetables, cereals, legumes, fish and olive oil), two
88 moderation components for which consumption is to be limited (meat and dairy products) and
89 an alcohol component. Each food group is divided into three categories using fixed cut-offs
90 (Supplemental Table 1). The cut-offs have been proposed by Sofi et al., based on a
91 comprehensive meta-analysis (32). For the beneficial food groups, 2 points are given to the
92 highest category of consumption, 1 to the middle category and 0 to the lowest category. A
93 reverse scoring is applied for the moderation components, that is, 2 points for the lowest
94 category, 1 for the middle category and 0 for the highest category. For the alcohol component,
95 the scoring was as follows: 2 points if the intake was comprised between 12-24g, 1 point if
96 <12g, 0 points if >24g. The final score ranges from 0 to 18 points (32).

97 In a sensitivity analysis, we also considered the Mediterranean Diet Scale (MDS) by
98 Trichopoulou et al. (12) which is based on the same components as the MEDI-LITE but the

99 attribution of points for each component depends on the sex-specific median. For beneficial
100 components, 1 point is assigned when the consumption is at or above the median and 0 point
101 when the consumption is below the median. For moderation components, 1 point is assigned
102 when the consumption is below the median, 0 otherwise. Regarding alcohol, 1 point is
103 attributed if the intake is comprised between 10-50g for men and 5-25g for women, 0 points
104 otherwise (12).

105

106 **Nutritional quality assessment**

107 Three *a priori* scores were used to assess overall nutritional quality of the diet. First, we
108 employed the food-based simplified *Programme National Nutrition Santé* Guidelines Score 2
109 (sPNNS-GS2), ranging from $-\infty$ to 14.25, which measures adherence to the French official
110 nutrition guidelines based on epidemiological evidence (33). Second, we constructed the
111 nutrient-based Probability of Adequate Nutrient intake Diet score (PANDiet), ranging from 0
112 to 100, which reflects adequacy of the diet to the current French nutrient reference values
113 (34). Third, we computed the comprehensive diet quality index (cDQI), which allows to
114 differentiate the consumption of healthful and unhealthful plant-based and animal food groups
115 (35). It ranges from 0 to 85 and includes seventeen components (eleven plant-based food and
116 six animal-based foods). Healthful plant- and animal-based foods are scored positively and
117 reversely for unhealthful plant- and animal-based foods. More information regarding the
118 computation of the cDQI is available elsewhere (35).

119

120 **Environmental impact assessment**

121 A detailed description of the development of the environmental indicators has been given
122 elsewhere (36). Briefly, the environmental indicators were assessed per day using the life
123 cycle assessment methodology and the system boundaries were cradle-to-farm. The following
124 indicators were used: GHGE in kgCO₂e/kg, the cumulative energy demand (CED) in MJ/kg,
125 and land occupation (LO) in m²/kg. A database associated with the Org-FFQ items was
126 created with the indicators, considering the food production system (conventional or organic).
127 For this purpose, a comprehensive tool named DIALECTE, developed by the non-profit
128 organisation Solagro, was used (37). It assesses the agro-environmental performance of
129 French farming systems, based on approximately 2,000 farms, including organic farms. The
130 environmental footprint of 60 agricultural items was estimated with this tool, completed by a
131 literature review for 32 products. The GHGE, CED and LO of each food item in both their
132 organic and conventional version were determined. The three diet-related environmental

133 outcomes were then obtained by multiplying the food quantity consumed (g/day) by each
134 respective environmental indicator value, considering the production system. The three diet-
135 related GHGE, CED, and LO were then obtained by multiplying the food quantity consumed
136 (g/day) by each respective environmental indicator value, considering the production system.

137

138 **Monetary cost assessment**

139 Participants were asked to complete a questionnaire in 2014 concerning attitudes and
140 motivations regarding food choices and food places of supply. The KANTAR® database
141 2012 was used to obtain the prices for each of the 264 food items according to the place of
142 supply and considering the method of food production (organic vs. conventional) (38).
143 Moreover, 1,962 additional prices were collected by the Bioconsom'acteurs association
144 between 2014 and 2015 to assess the price of each food item in short supply chains. We
145 obtained the individual monetary cost by multiplying the price (€/g) by the quantities
146 consumed (g/d) considering the place of supply and the food production system.

147

148 **Pesticide exposure assessment**

149 Data regarding pesticide residues came from the Chemisches und Veterinäruntersuchungsamt
150 Stuttgart (CVUAS) database. The CVUAS (39) is an official regional state food control and
151 health laboratory located in Germany, which analyses pesticides and contaminants in plant-
152 source products, available on the German market but the products come from 88 countries.
153 This database does not contain any animal products; however, data are available for both
154 organically- and conventionally-grown products. Since all products are from the German
155 market, they are subject to the European Union standards (as France) regarding organic
156 agriculture (40). In the present work, analytical results for 4 years (2012-2015) were used,
157 leading to a database comprising more than 6.7 million data points (including 1 million for
158 organic plant foods). Amongst molecules available in the CVUAS database, for which a
159 sufficient number of plant foods was covered (for instance the dithiocarbamates were not
160 retained due to lack of data despite their frequent quantification in plant products), we
161 selected some twenty pesticides, given their frequency of quantification exceeding the
162 maximum residue levels and their frequency above toxicological reference values, using data
163 from the 2015 EFSA report (41), as described elsewhere (42). Three active substances
164 authorised in organic farming were additionally included. The estimated daily intake (EDI)
165 (expressed in µg/kg of weight per day) under the lower-bound scenario for each pesticide and
166 each participant was calculated using the following formula (43):

167
$$EDI = \sum_{k=1}^{n_i} E_{i,j} = (C_{i,k} \times L_{k,j}) \div BW_i$$

168 $E_{i,j}$ estimated daily exposure to pesticide j for the individual i ($\mu\text{g}/\text{kg}$ bw/day).

169 n_i number of plant foods in the diet of individual i .

170 $C_{i,k}$ mean daily intake of plant food k by individual i (g/day).

171 $L_{k,j}$ concentration of pesticide j in food k (mg/kg).

172 BW_i body weight of individual i (kg).

173

174 **Assessment of practices associated with the Mediterranean lifestyle**

175 Certain specific practices are related to the Mediterranean lifestyle, beyond diet composition,
176 therefore, we also investigated, through different sociocultural different proxy markers of the
177 Mediterranean lifestyle, whether adherence to the Mediterranean diet was associated with
178 physical activity, consumption frequency of ready-to-use products and consumption of
179 organic food. Physical activity levels, as marker of recommended physical activity, were
180 determined using the International Physical Activity Questionnaire (44,45). Three levels of
181 physical activity were established based on the Metabolic Equivalent of Task (MET) minutes
182 per week (MET-min/week): low (< 600 MET-min/week), moderate (600 to 1500 MET-
183 min/week) and high (> 1500 MET-min/week).

184 The consumption frequency of ready-to-use products was also examined as a marker of proxy
185 of culinary activities or sociality around food. In the aforementioned questionnaire used to
186 retrieve food supply places, a question pertaining to the consumption frequency of canned,
187 chilled, and frozen foods, was also asked. These consumptions were declared by each
188 participant through 5 categories: never, rarely, half of the time, often and always and a
189 weighting of 0, 0.25, 0.5, 0.75 and 1 point was assigned to each category. The final score is
190 the sum of points multiplied by the weighting(46).

191 The organic food proportion in the diet was evaluated, as a marker of eco-friendly product
192 consumption, as the ratio of total food consumed in organic (g/d) to total food consumed (g/d)
193 without water.

194

195 **Statistical analyses**

196 NutriNet-Santé participants who filled out the Org-FFQ between June and December 2014
197 were included in the present study (N=37,685). Of these, we excluded participants with
198 missing covariates (N=380), who were detected as under or over-reporters and who were
199 living overseas (N=2852), and with missing data regarding the place of supply for the

200 computation of diet monetary cost (N=5243), leaving a sample of 29,210 participants
201 **(Supplemental Figure 1)**. Participants were ranked and divided into sex-specific quintiles
202 (Qi), according to the MEDI-LITE distribution. Baseline participants characteristics across
203 levels of adherence to the Mediterranean diet were presented as mean \pm standard deviation
204 (SD). P-values refer to tests for linear contrast across quintiles for continuous variables, and
205 Mantel-Haenszel chi-square trend tests or chi-square test, for ordinal and categorial variables,
206 respectively.

207 Normality was assessed using graphical methods (histograms and Q-Q plots). To identify the
208 associations between each sustainability indicator and adherence to the Mediterranean diet,
209 analyses of covariance (ANCOVA) models, with Tukey adjustment, according to the
210 observed margins, were used, providing adjusted means and 95% confidence intervals (CI).
211 Two different models were computed: a model which was unadjusted (model 1) and a model
212 adjusted for age, sex and total daily energy intake (main model, model 2). The latter model
213 enabled us to study diet composition *per se*, beyond energy intake. P-values across quintiles
214 were estimated using linear contrast tests.

215 The relationships between the various indicators and adherence to Mediterranean diet were
216 also examined using the MEDI-LITE as a continuous variable, and results were expressed as
217 beta-coefficient (β) per 1 SD and 95%CI.

218 Sensitivity analyses were also performed to assess the robustness of our results by computing
219 the MDS. Thus, the same analyses were performed to evaluate the associations between each
220 sustainability indicator and adherence to the Mediterranean diet, using the MDS.

221 To allow comparability, the two Mediterranean scores were standardised in models with the
222 main exposure modelled as a continuous variable. Two-sided tests were used and a P-value
223 <0.05 was set for statistical significance. SAS (version 9.4; SAS Institute, Inc.) was used to
224 perform data management and statistical analyses.

225

226 **Results**

227 **Sample characteristics**

228 The MEDI-LITE in the study sample ranged from 1 to 18 (32). **Table 1** shows the
229 characteristics of the study sample across quintiles of adherence to the MEDI-LITE. By
230 construction, participants in Q1 were the least adherent (6.05 (SD=1.13)) to the
231 Mediterranean diet, and those in Q5 were the most adherent (13.94 (SD=1.06)). Participants
232 with the highest adherence to the Mediterranean diet were the oldest. Postgraduate

233 participants represented 63.62% of Q1 and 67.16% of Q5. The lowest proportion of
234 employees and manual workers was found in Q5 and the highest proportions of participants
235 with high-level incomes were found in the highest quintiles.

236 Participants in Q5 were more often never-smokers and less often current smokers than other
237 quintiles. Regarding the body mass index, participants in Q1 had a mean of 24.63 kg.m⁻²
238 (SD=5) and those in Q5 had a mean of 23.45 kg.m⁻² (SD=4.07).

239

240 **Adherence to the Mediterranean diet and diet sustainability**

241 **Supplemental Table 2** shows the intake for the different MEDI-LITE components.
242 Adherence to the Mediterranean diet, modelled as quintiles, and the different diet
243 sustainability features are presented in **Figure 1** (multivariable models). A positive
244 association was observed between adherence to the MEDI-LITE score and the sPNNS-GS2
245 (Q5 vs. Q1: +470%), the PANDiet (Q5 vs. Q1: +15%), and the cDQI (Q5 vs. Q1: +22%). LO
246 (Q5 vs. Q1: -35%), GHGE (Q5 vs. Q1: -15%) and CED (Q5 vs. Q1: -17%) decreased across
247 quintiles. Diet monetary cost gradually increased across quintiles, the differences between Q5
248 compared with Q1 were 1.05€/day for the total diet monetary cost (Q5 vs. Q1: +15%), -
249 1.72€/day for the cost dedicated to conventional foods (Q5 vs. Q1: -29%) and 2.76€/day for
250 the cost dedicated to organic foods (Q5 vs. Q1: +204%).

251 Unadjusted models pertaining to the associations between the various sustainability indicators
252 and the MEDI-LITE are shown in **Supplemental Table 3**. Overall, the same trends were
253 observed, apart from CED, for which the unadjusted models yielded opposite results.

254 Regarding nutrients (adjusted models), total energy intake gradually increased across MEDI-
255 LITE quintiles while intake of ethanol decreased (**Table 2**). Higher adherents to the MEDI-
256 LITE had lower contribution to energy-intake of saturated fatty acids, and added sugars and
257 higher contribution of mono-unsaturated fatty acids, poly-unsaturated fatty acids and
258 carbohydrates. The intake of proteins from plant origin, fibre, vitamins C and E were the
259 highest in Q5 and the lowest in Q1. Adherence to the MEDI-LITE was negatively associated
260 with the intake of vitamin B12.

261 **Table 3** presents the dietary exposure to different pesticides using the lower-bound scenario.
262 In adjusted models, in line with the greater intakes of plant-based products in Q5 participants
263 compared to Q1 participants (Supplemental Table 2), higher levels of adherence to the MEDI-
264 LITE were overall associated with higher pesticide exposure (higher values observed in the
265 highest quintiles), except for chlorpropham for which the association was inverse and
266 imidacloprid for which no association was observed.

267

268 **Adherence to the Mediterranean diet and practices associated with the Mediterranean**
269 **lifestyle**

270 The highest proportion of individuals with elevated physical activity was observed in Q5
271 (**Table 4**). Higher adherence to the MEDI-LITE was also related to higher organic food
272 consumption (Q5 vs. Q1: +171%). Positive associations were also observed between
273 adherence to the MEDI-LITE while consumption of ready-to-use products decreased with
274 adherence to the MEDI-LITE.

275

276 The results pertaining to the MDS are shown in **Supplemental Tables 4, 5, 6, and 7**.
277 Associations between diet sustainability and the MEDI-LITTE and the MDS per 1 SD are
278 shown in Supplemental Figure 2. Overall, the same findings were observed. Further
279 adjustment for education level did not substantially change the results (data not shown).

280

281 **Discussion**

282 Using a multi-criteria analysis, the present study evaluated diet sustainability according to
283 various levels of adherence to the Mediterranean diet, as reflected by the MEDI-LITE score,
284 using a large adult sample from the NutriNet-Santé cohort.

285 Our evaluation encompassed various indicators including nutrient intakes, dietary scores,
286 environmental pressures, monetary cost, and dietary pesticide exposure. In this French adult
287 population, following a Mediterranean dietary pattern was associated with nutritional and
288 environmental benefits, although higher adherence was also accompanied by overall higher
289 pesticide exposure and additional monetary costs.

290 To our knowledge, this is the first study which simultaneously considers all these indicators,
291 in particular pesticide exposure, thus allowing a thorough evaluation of the sustainability of
292 this dietary pattern.

293

294 The nutritional benefits of the Mediterranean diet have been extensively described. With
295 regard to overall nutritional quality scores (reflecting both food- and nutrient-based
296 recommendations) and nutrient intakes, our results are thus in line with those of previous
297 studies (20), indicating a high nutritional quality associated with the adherence to the
298 Mediterranean diet. These results are also in accordance with a work by Aboussaleh et al.
299 which also reported that individuals following a Mediterranean diet more often met

300 recommended nutrient and micronutrient intakes (47,48). It should be noted that the
301 recommended intake for alcohol in the Mediterranean diet is much higher than the official
302 French national guideline (33).

303

304 In accordance with the literature, we observed that, in energy-adjusted models, higher
305 adherence to the Mediterranean diet, as expressed by the MEDI-LITE, was associated with
306 lower overall environmental impact (Q5 vs. Q1: -15%, -35, -17%, for GHGE, LO and CED,
307 respectively) (20). Several studies conducted in other Mediterranean countries (Italy, Spain
308 and Lebanon) have thus produced comparable findings (21,49–51). This is explained by the
309 fact that the Mediterranean diet encourages the consumption of plant-based foods, including
310 fruit and vegetables, whole grains, legumes and nuts, which exhibit lower overall
311 environmental impacts than animal-based foods (19,36,52). The carbon footprint of the
312 Mediterranean diet has been extensively studied (20). In adjusted models, total GHGE were
313 2.93 kgCO₂eq/day among high-adherent participants. In a study conducted in Spain, the
314 Mediterranean diet was found to have GHGE levels in line with our findings (2.79
315 kgCO₂eq/day) (22). Of note, the system boundaries considered in the Spanish study were not
316 the same as ours. The value for GHGE for strong adherents to the Mediterranean diet in the
317 present study is lower than that of omnivores (4.16 kgCO₂eq/day) but more than twice as high
318 than that of vegans (1.17 kgCO₂eq/day) observed in a previous work that we carried out in the
319 NutriNet-Santé cohort (53). Our findings are partially in line with a simulation study
320 performed on a global level (19). Interestingly, energy-adjustment appeared to reverse the
321 relationships in the case of CED, emphasising that excessive energy intake is a strong
322 contributor to overall environmental impact. In addition, the reduction in emissions is in line
323 with the frugality aspect promoted by the Mediterranean lifestyle.

324

325 Regarding the economic dimension, we observed that participants reporting higher adherence
326 to the Mediterranean diet exhibited slightly higher monetary costs than other groups (in
327 energy-adjusted models). This is in line with some previous studies showing extra-cost
328 associated with adherence to the Mediterranean diet pattern (21,54). A study showed that
329 following a Western diet was less expensive than following a Mediterranean diet (21). In our
330 study, participants who adhered the most to the Mediterranean diet spent 1.05€ extra per day.
331 According to a recent systematic review, the Mediterranean diet is not more expensive than
332 other diets, but varies greatly (3.33 and 14.42€/ d per capita) according to the region, food
333 brand, season, and stores. In some cases, the costs can be the same as for other diets (20). In

334 the present work, individuals who adhered the most to the Mediterranean diet were also those
335 who had higher intake of organic food, explaining the higher monetary cost. In our study,
336 adjustment for energy intake tended to lower the cost difference, which is consistent with the
337 findings of a work conducted in Spain comparing various dietary patterns (22). In our
338 analysis, we distinguished the prices of organic from conventional foods, this may have led to
339 higher diet monetary cost compared with other studies, in addition to methodological
340 differences. The increase in monetary cost of 15% for the highest adherence level raises a
341 concern about affordability for the fraction of the population with limited incomes. Following
342 the Mediterranean diet was approximately 1€/d more expensive. Although this value is an
343 estimate and does not represent the actual cost difference, this difference still reflects food
344 inequality. One euro per day may constitute a substantial burden for disadvantaged
345 households. For instance, in an intervention study carried out in a socially deprived districts of
346 Marseille (France), individuals spent on average 3.65€/d per person for food consumed at
347 home (55). This should encourage national authorities to subsidise environmentally
348 sustainable and healthy diets such as the Mediterranean diet to allow as many people as
349 possible to access this diet and benefit from the reduced environmental and health impacts
350 associated with it. The Mediterranean diet has been described as a sustainable diet by several
351 conceptual studies (56–58). However, safety aspects are rarely considered and few studies
352 have investigated pesticide exposure associated with adherence to the Mediterranean diet. It is
353 known that plant foods are the most contaminated food groups by pesticide residues while
354 organic plant foods are less contaminated than their conventional counterparts (59). In the
355 present work, due to their greater consumption of cereals, fruits, vegetables, participants in
356 highest quintiles were more exposed to pesticide residues than individuals in lowest quintiles
357 (Q1 and Q2). Thus, intakes of less pesticide-contaminated organically grown foods did not
358 appear to fully compensate for the higher exposure from high intake of conventional foods of
359 plant origin among these participants. In contrast, another study based on the NutriNet-Santé
360 cohort showed that individuals with a very high contribution of organic food in their diet (on
361 average 70% of food coming from organic sources) had a reduced exposure to food pesticide
362 residues compared to individuals with null or low contribution of organic food in the diet
363 (42). The higher discrimination between the two extreme quintiles in terms of share of
364 organic in the diet (71% (Q5) vs. 0% (Q1)) in the latter study as compared in the present
365 study (46% vs. 17%) also explains the differences regarding pesticide exposure between the
366 two studies. It was also observed during a controlled trial that a Mediterranean diet combined
367 with full organic food intake reduced total pesticides exposure by >90%, while increasing

368 conventional fruit and vegetable consumption led to higher levels of pesticide exposure (60).
369 In a recent study carried out in the US, consumption of certain foods, such as legumes and
370 grains, was the primary contributor to total dietary glyphosate body burden rather than diet
371 style (Mediterranean-style and Vegetarian eating pattern) (61). Pesticide exposure through
372 diet in the general population has been associated with adverse health outcomes (7,8). In a
373 recent US study based on three large adult cohorts, a diet rich in low-pesticide contaminated
374 fruit and vegetables reduced mortality whereas a comparable diet with high-pesticide
375 contaminated fruit and vegetables had no longer a significant protective effect (6). However,
376 the healthiness of the Mediterranean diet probably outweighs the potential deleterious effect
377 of the exposure to pesticides, given the very large literature showing its possible health
378 benefits (16), although, more data are needed to quantify this precisely. Particular attention
379 should also be paid to seafood since these products are source of contamination of persistent
380 organic pollutants, furans or polychlorinated biphenyls (62). This is of importance and needs
381 further consideration since sustainable diets, as defined by the FAO, are supposed to provide
382 “safe foods” (11). This indicates the need to generalise production methods limiting
383 agricultural inputs to maximise the health benefits of plant-rich diets such as the
384 Mediterranean diet. A recent study conducted in Australia somewhat supports this idea (63).
385 In this study, a dietary shift towards recommended dietary patterns was associated with a
386 higher environmental pesticide toxicity footprint, leading the authors to conclude that actions
387 in the agricultural sector might be the best approach to reduce the environmental burden
388 associated with pesticides.

389 We also examined the associations between adherence to the Mediterranean diet and other
390 components of the Mediterranean lifestyle (apart from the diet composition *per se*). We
391 observed that individuals who adhered to the Mediterranean diet were more often physically
392 active and less often prone to eat ready-to-use products and therefore more likely to have
393 varied culinary and cooking practices. Furthermore, the Mediterranean diet now also
394 emphasises the importance of eco-friendly products (15). We observed here a strong positive
395 association between organic food consumption and adherence to the Mediterranean diet,
396 which is of interest since organic food consumption has been associated with biodiversity
397 benefits (64). Therefore, individuals who followed Mediterranean dietary patterns appeared to
398 be more likely to also follow the principles of a Mediterranean lifestyle, thereby increasing
399 possible health benefit.

400

401 Some limitations should be noted. First, the NutriNet-Santé cohort study includes volunteers,
402 who are probably more interested in nutrition and health issues than the general population,
403 leading to a health-conscious sample with healthier eating habits and probably higher
404 adherence to the Mediterranean diet than the French adult population (65). It has also been
405 shown that NutriNet-Santé participants tend to exhibit a higher socioeconomic status than the
406 general population (66). It is likely that some population subgroups, such as deprived
407 individuals or individuals who are not-Internet users (e.g. computer illiteracy) are not
408 included or underrepresented in the cohort. **Therefore, caution is needed before generalising**
409 **the results to the French population.** Moreover, food consumption data were self-reported
410 using a food frequency questionnaire, making some degree of measurement error inevitable.
411 Total food intake may have thus been overestimated (67), and possibly a desirability bias may
412 have occurred. Furthermore, the questions used to estimate the share of organic food in the
413 diet had not been validated. Nonetheless, the original FFQ used to develop the Org-FFQ has
414 been validated against dietary records (27), and all lifestyle and anthropometric questionnaires
415 have been validated against traditional methods (68,69). In addition, fish is one of the most
416 important beneficial components of the Mediterranean diet but while we did not have the
417 most relevant indicators to assess its environmental impact, we do know that 60% of fish
418 stocks are fully exploited and 30% overexploited (2). Regarding environmental indicators,
419 biodiversity and water use should be also accounted for in future studies, in particular due to
420 the high water footprint of some products such as nuts (70), for which we had very limited
421 data. Furthermore, we only assessed pesticide exposure through foods of plant origin since
422 they are the primary contributors. However, we may have underestimated the overall pesticide
423 impact, in particular among participants eating more animal-based foods. In addition, we did
424 not consider potential nutritional differences between organic and conventional products due
425 to lack of data. Lastly, dietary data and related sustainability outcomes were collected in
426 2014, almost ten years ago, and the food system has been through and is still going through
427 multiple crises (including Covid-19 pandemic, the massive acceleration of climate change,
428 invasion of Ukraine and inflation). As a result – more than dietary patterns themselves which
429 are relatively constant over time – diet-related costs observed in the current study do not
430 reflect the current situation (e.g. inflation and reduction of organic purchase among low-
431 income households). Similarly, pesticide exposure patterns may have changed since 2014
432 (e.g. ban of certain molecules and introduction of new ones). However, overall, the extent of
433 food sample contaminations did not noticeably changed during this time period (41,59). Our
434 study has also several strengths. This is the first study to concomitantly consider multiple

435 criteria (using a wide range of indicators related to sustainability) and describe the pesticide
436 exposure in relation to Mediterranean diet sustainability. In addition, we were able to
437 distinguish organic from conventional food intakes. We also attempted to account for the
438 other principles of the Mediterranean lifestyle. Finally, our study was based on a large sample
439 allowing an important diversity of dietary patterns and profiles.

440

441

442 **Conclusions**

443 In this population of French adults, adherence to the Mediterranean diet was associated with
444 higher nutritional quality and overall lower environmental impact. However, adherence to the
445 Mediterranean diet (based on high intake of foods from plant origin) was overall positively
446 associated with pesticide residue exposure which was not fully counterbalanced by the higher
447 consumption of organic food. This underscores the importance of implementing political
448 strategies aiming to generalise production methods limiting pesticide residue exposure. The
449 higher monetary cost may also be a barrier for acceptance and highlights the urgent need for
450 strategies aiming to promote affordable, nutritious but also safe and environmentally
451 sustainable diets for all.

452

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473

474 **Author contributions**

475 The authors' responsibilities were as follows: JBau, DL, BA, BL, SH, PP, and EK-G: led the
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477 JA, PP and EK-G: contributed to interpretation of results and provided critical revisions to the
478 manuscript; JBau and FN: performed statistical analysis, wrote the paper and had full access
479 to all the data in the study; JBau: had primary responsibility for the final content and takes
480 responsibility for the integrity of the data and the accuracy of the data analysis as guarantor;
481 and all authors: read and approved the final manuscript.

482

483 **Conflict of Interest**

484 None.

485

486

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536 [2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%200www.ncbi.nlm.nih.gov](https://www.nejm.org/doi/10.1056/NEJMoa1200303?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%20%200www.ncbi.nlm.nih.gov)
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Table 1: General characteristics according to sex-specific quintiles of adherence to the Mediterranean diet (MEDI-LITE), n=29,210, 2014, NutriNet-Santé study¹

	Quintiles of level of adherence to the Mediterranean diet					P ²
	Q1	Q2	Q3	Q4	Q5	
MEDI-LITE	6.05 (1.13)	8.54 (0.50)	10.00 (0.00)	11.45 (0.50)	13.94 (1.06)	<.0001
Age, years	49.69 (14.88)	53.20 (14.13)	54.27 (13.73)	55.24 (13.23)	55.18 (13.21)	<.0001
Women, %	75.14	75.21	75.15	74.29	73.97	0.39
Education level, %						0.0001
Less than high-school diploma	20.95	22.36	22.83	21.02	19.40	
High school diploma	15.43	14.92	14.59	14.73	13.44	
Postgraduate	63.62	62.72	62.58	64.25	67.16	
Occupation status, %						<.0001
Unemployed	4.30	3.65	3.86	3.98	4.66	
Never employed	7.24	6.63	5.97	6.43	8.14	
Self-employed, Farmer	1.77	1.74	1.45	1.78	1.93	
Employee, Manual worker	18.60	15.33	13.57	12.95	10.91	
Intermediate professionals	16.52	14.91	14.71	13.94	13.53	
Managerial staff	22.59	20.76	21.00	20.70	20.18	
Retired	28.98	36.98	39.44	40.23	40.66	
Monthly income per unit household unit, %						<.0001
Unwilling to answer	5.87	5.83	6.21	6.04	6.40	
< €1,200	13.34	11.45	10.50	10.72	11.87	
€1,200-1,800	26.01	22.98	22.61	21.98	22.22	
€1,800-2,700	27.24	28.26	28.30	27.22	26.44	
> €2,700	27.54	31.48	32.37	34.04	33.07	
Region, %						<.0001
Parisian basin	17.57	14.98	14.28	13.77	12.19	
East Center	13.73	14.49	14.35	14.37	14.61	
East	8.97	8.91	8.09	7.86	7.06	
Mediterranean	10.13	11.70	13.33	14.39	16.55	
North	4.87	4.15	3.28	2.96	2.76	
West	14.34	14.29	14.90	15.58	15.48	
Parisian area	19.90	20.21	19.69	19.69	19.29	
South West	10.48	11.27	12.07	11.39	12.06	
Smoking habits, %						
Never smoker	50.22	48.75	48.89	48.61	47.51	
Former smoker	36.43	39.79	40.73	41.76	43.60	
Current smoker	13.34	11.46	10.38	9.62	8.89	
Body mass index, kg.m²	24.63 (5.00)	24.48 (4.77)	24.30 (4.69)	24.10 (4.47)	23.45 (4.07)	<.0001

95%CI: 95% confidence interval; MEDI-LITE: Literature-based adherence score to the Mediterranean diet; Q: quintiles.

¹Values are means (standard deviation) or %, as appropriate.

²P-values are based on linear contrast tests for continuous variables, and Mantel-Haenszel chi-square and chi-square tests for ordinal or categorical variables, respectively.

Figure 1: Associations between adherence to the Mediterranean diet (MEDI-LITE) and diet sustainability indicators (mean and 95%CI), n=29,210, 2014, NutriNet-Santé study^{1,2}

95%CI: 95% confidence interval; cDQI: Comprehensive Diet Quality Index; CED: Cumulative Energy Demand; GHGE: Greenhouse gas emissions; LO: Land Occupation; MEDI-LITE: Literature-based adherence score to the Mediterranean diet; PANDiet: Diet Quality Index Based on the Probability of Adequate Nutrient Intake; Q: quintiles; sPNNS-GS2: simplified Programme National Nutrition Santé-Guideline Score. cDQI, PANDiet, and sPNNS-GS range from 0 to 85, 0 to 100, and $-\infty$ to 14.25, respectively. CED, GHGE, and LO are expressed in MJ/d, kgCO₂eq/d, m²/d, respectively. Costs are expressed in €/d.

¹P-values are based on linear contrast tests. All P-values <.0001

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

Table 2: Associations between adherence to the Mediterranean diet (MEDI-LITE) and nutrient intakes, n=29,210, 2014, NutriNet-Santé study

	Quintiles of level of adherence to the Mediterranean diet										Per SD			
	Q1		Q2		Q3		Q4		Q5		P ¹	β	95%CI	P ²
	mean	95%CI	mean	95%CI	mean	95%CI	mean	95%CI	mean	95%CI				
Total energy intake, kcal/day														
<i>Model 1³</i>	1759	1743; 1776	1891	1877; 1905	2002	1984; 2021	2111	2097; 2125	2250	2234; 2267	<.0001	169.65	162.7; 176.6	<.0001
<i>Model 2⁴</i>	1765	1749; 1781	1893	1879; 1907	2003	1985; 2021	2108	2094; 2121	2246	2230; 2262	<.0001	166.58	159.8; 173.4	<.0001
%Total fat														
<i>Model 1³</i>	41.11	40.93; 41.30	41.09	40.92; 41.25	40.98	40.76; 41.19	41.27	41.11; 41.44	41.63	41.44; 41.82	<.0001	0.18	0.10; 0.27	<.0001
<i>Model 2⁴</i>	41.29	41.10; 41.48	41.10	40.94; 41.26	40.94	40.72; 41.15	41.20	41.04; 41.37	41.57	41.38; 41.76	<.0001	0.1	0.02; 0.18	0.01
%Saturated fatty acids														
<i>Model 1³</i>	16.62	16.53; 16.71	15.59	15.51; 15.67	14.95	14.85; 15.06	14.35	14.27; 14.43	13.01	12.92; 13.10	<.0001	-1.23	-1.26; -1.19	<.0001
<i>Model 2⁴</i>	16.64	16.55; 16.73	15.59	15.51; 15.67	14.95	14.85; 15.06	14.34	14.26; 14.42	13.00	12.91; 13.09	<.0001	-1.24	-1.28; -1.20	<.0001
%Mono-unsaturated fatty acids														
<i>Model 1³</i>	15.40	15.30; 15.51	15.98	15.89; 16.07	16.28	16.16; 16.40	16.76	16.67; 16.86	17.58	17.47; 17.69	<.0001	0.75	0.70; 0.79	<.0001
<i>Model 2⁴</i>	15.48	15.38; 15.59	15.98	15.89; 16.08	16.26	16.14; 16.38	16.73	16.64; 16.83	17.56	17.45; 17.66	<.0001	0.71	0.67; 0.76	<.0001
%Poly-unsaturated fatty acids														
<i>Model 1³</i>	6.02	5.96; 6.09	6.44	6.39; 6.50	6.69	6.62; 6.76	7.09	7.04; 7.15	8	7.93; 8.07	<.0001	0.67	0.64; 0.70	<.0001
<i>Model 2⁴</i>	6.08	6.01; 6.14	6.45	6.39; 6.50	6.68	6.60; 6.75	7.07	7.01; 7.13	7.98	7.91; 8.05	<.0001	0.65	0.62; 0.68	<.0001
%Carbohydrates														
<i>Model 1³</i>	38.28	38.08; 38.48	39.09	38.92; 39.26	39.8	39.58; 40.03	40.06	39.88; 40.23	41	40.80; 41.20	<.0001	0.93	0.85; 1.02	<.0001
<i>Model 2⁴</i>	38.00	37.80; 38.20	39.07	38.90; 39.24	39.86	39.64; 40.08	40.18	40.01; 40.35	41.12	40.92; 41.32	<.0001	1.07	0.99; 1.16	<.0001
%Added sugars														
<i>Model 1³</i>	6.46	6.38; 6.54	5.58	5.51; 5.65	5.26	5.17; 5.36	4.89	4.82; 4.96	4.33	4.25; 4.42	<.0001	-0.73	-0.76; -0.69	<.0001
<i>Model 2⁴</i>	6.32	6.24; 6.40	5.58	5.51; 5.64	5.29	5.20; 5.38	4.95	4.88; 5.02	4.39	4.30; 4.47	<.0001	-0.66	-0.70; -0.63	<.0001
%Proteins														
<i>Model 1³</i>	20.2	20.11; 20.30	19.42	19.34; 19.50	18.82	18.72; 18.93	18.29	18.21; 18.37	17.01	16.91; 17.11	<.0001	-1.1	-1.14; -1.06	<.0001
<i>Model 2⁴</i>	20.32	20.22; 20.41	19.43	19.35; 19.51	18.80	18.70; 18.91	18.24	18.16; 18.32	16.96	16.87; 17.06	<.0001	-1.16	-1.20; -1.12	<.0001
Protein from plant origin, g/day														
<i>Model 1³</i>	20.75	20.46; 21.03	24.68	24.43; 24.93	27.78	27.45; 28.10	31.4	31.14; 31.65	39.19	38.90; 39.48	<.0001	6.29	6.17; 6.42	<.0001
<i>Model 2⁵</i>	23.67	23.44; 23.90	26.07	25.87; 26.26	26.07	27.53; 28.04	30.06	29.86; 30.26	36.06	35.83; 36.29	<.0001	4.22	4.13; 4.32	<.0001
Fibre, g/day														
<i>Model 1³</i>	15.47	15.23; 15.72	19.97	19.76; 20.19	23.03	22.75; 23.30	26.23	26.02; 26.45	32.48	32.23; 32.73	<.0001	5.8	5.69; 5.90	<.0001
<i>Model 2⁵</i>	18.15	17.95; 18.36	21.10	20.92; 21.27	22.96	22.73; 23.19	25.02	24.84; 25.20	29.86	29.66; 30.07	<.0001	3.98	3.89; 4.07	<.0001
Poly-unsaturated fatty acids, g/day														
<i>Model 1³</i>	11.37	11.18; 11.57	13.12	12.95; 13.28	14.46	14.24; 14.68	16.13	15.96; 16.30	19.57	19.37; 19.76	<.0001	2.79	2.71; 2.87	<.0001
<i>Model 2⁵</i>	13.38	13.23; 13.53	13.99	13.86; 14.12	14.42	14.26; 14.59	15.22	15.09; 15.35	17.56	17.41; 17.71	<.0001	1.41	1.35; 1.48	<.0001
Omega-3 fatty acids, g/day														
<i>Model 1³</i>	1.38	1.35; 1.42	1.8	1.76; 1.83	2.04	2.00; 2.08	2.39	2.35; 2.42	3.03	3.00; 3.07	<.0001	0.56	0.55; 0.58	<.0001
<i>Model 2⁵</i>	1.69	1.66; 1.72	1.91	1.89; 1.94	2.03	1.99; 2.07	2.25	2.22; 2.28	2.75	2.72; 2.78	<.0001	0.36	0.35; 0.37	<.0001
EPA, g/day														
<i>Model 1³</i>	0.12	0.11; 0.12	0.17	0.17; 0.17	0.19	0.19; 0.20	0.23	0.22; 0.23	0.26	0.25; 0.26	<.0001	0.05	0.05; 0.05	<.0001
<i>Model 2⁵</i>	0.14	0.14; 0.15	0.18	0.18; 0.19	0.19	0.19; 0.20	0.21	0.21; 0.22	0.24	0.23; 0.24	<.0001	0.0322	0.030; 0.034	<.0001

DHA, g/day														
<i>Model 1</i> ³	0.15	0.15; 0.16	0.22	0.22; 0.23	0.25	0.25; 0.26	0.29	0.29; 0.30	0.33	0.32; 0.33	<.0001	0.06	0.06; 0.06	<.0001
<i>Model 2</i> ⁵	0.19	0.18; 0.19	0.24	0.23; 0.24	0.25	0.25; 0.26	0.28	0.27; 0.28	0.28	0.29; 0.30	<.0001	0.04	0.04; 0.04	<.0001
Vitamin C, mg/day														
<i>Model 1</i> ³	108.3	106.0; 110.6	136.3	134.3; 138.2	156	153.4; 158.6	169.7	167.7; 171.7	194.3	192.0; 196.7	<.0001	29.47	28.48; 30.45	<.0001
<i>Model 2</i> ⁵	123.6	121.4; 125.7	142.8	140.9; 144.6	155.6	153.2; 158.0	162.8	160.9; 164.7	179.3	177.1; 181.4	<.0001	18.99	18.07; 19.91	<.0001
Vitamin E, mg/day														
<i>Model 1</i> ³	10.74	10.56; 10.91	12.83	12.68; 12.98	14.35	14.15; 14.54	16.01	15.85; 16.16	19.19	19.01; 19.36	<.0001	2.88	2.81; 2.96	<.0001
<i>Model 2</i> ⁵	12.58	12.45; 12.72	13.61	13.49; 13.72	14.30	14.15; 14.45	15.17	15.06; 15.29	17.37	17.23; 17.51	<.0001	1.62	1.56; 1.68	<.0001
Vitamin B12, mg/day														
<i>Model 1</i> ³	5.83	5.68; 5.97	6.44	6.31; 6.57	6.61	6.44; 6.78	6.94	6.81; 7.07	6.63	6.48; 6.78	<.0001	0.27	0.21; 0.33	<.0001
<i>Model 2</i> ⁵	6.84	6.71; 6.98	6.84	6.73; 6.96	6.57	6.42; 6.73	6.48	6.36; 6.60	5.68	5.55; 5.82	<.0001	-0.42	-0.47; -0.36	<.0001
Calcium, mg/day														
<i>Model 1</i> ³	1100	1088; 1112	1113	1102; 1123	1125	1112; 1139	1133	1123; 1144	1101	1089; 1113	0.24	0.28	-4.88; 5.45	0.91
<i>Model 2</i> ⁵	1223	1214; 1231	1166	1159; 1173	1123	1114; 1133	1078	1071; 1085	978	970; 987	<.0001	-84.76	-88.4; -81.1	<.0001
Ethanol, g/day														
<i>Model 1</i> ³	9	8.67; 9.34	8.54	8.25; 8.83	8.44	8.06; 8.82	8.5	8.21; 8.79	8.07	7.73; 8.41	0.0003	-0.22	-0.37; -0.08	<.0001
<i>Model 2</i> ⁵	10.78	10.47; 11.09	9.15	8.89; 9.42	8.35	8.01; 8.70	7.68	7.42; 7.95	6.57	6.26; 6.88	<.0001	-1.36	-1.50; -1.23	<.0001

95% CI: 95% confidence interval; DHA: Docosahexaenoic acid; EPA: Eicosapentaenoic acid; MEDI-LITE: Literature-based adherence score to the Mediterranean diet; Q: quintiles.

¹P values are based on linear contrast tests.

²P-values are calculated by linear regression.

³Model 1: unadjusted.

⁴Model 2: adjusted for age and sex.

⁵Model 2: adjusted for age, sex, and daily energy intake using the residual method (71).

Table 3: Associations between adherence to the Mediterranean diet (MEDI-LITE) and dietary exposure to pesticides from plant-based foods, n=29,210, 2014, NutriNet-Santé study

	Quintiles of level of adherence to the Mediterranean diet										Per SD			
	Q1		Q2		Q3		Q4		Q5		P ¹	β	95% CI	P ²
	mean	95%CI	mean	95%CI	mean	95%CI	mean	95%CI	mean	95%CI				
Acetamiprid														
<i>Model 1³</i>	0.042	0.0402; 0.0438	0.0481	0.0465; 0.0496	0.0536	0.0516; 0.0557	0.0538	0.0522; 0.0553	0.0518	0.0500; 0.0536	<.0001	0.0037	0.0030; 0.0045	<.0001
<i>Model 2⁴</i>	0.0437	0.0419; 0.0455	0.0484	0.0469; 0.0499	0.0533	0.0513; 0.0553	0.0531	0.0515; 0.0546	0.0508	0.0490; 0.0526	<.0001	0.0028	0.0020; 0.0036	<.0001
Anthraquinone														
<i>Model 1³</i>	0.0005	0.0005; 0.0006	0.0006	0.0005; 0.0006	0.0006	0.0005; 0.0006	0.0006	0.0006; 0.0007	0.0007	0.0006; 0.0007	<.0001	0	0.0000; 0.0001	<.0001
<i>Model 2⁴</i>	0.0005	0.0005; 0.0006	0.0006	0.0005; 0.0006	0.0006	0.0006; 0.0006	0.0006	0.0006; 0.0006	0.0006	0.0006; 0.0007	0.003	0	0.0000; 0.0000	0.006
Azadirachtin														
<i>Model 1³</i>	0.0002	0.0001; 0.0002	0.0003	0.0002; 0.0003	0.0003	0.0003; 0.0003	0.0004	0.0004; 0.0004	0.0006	0.0006; 0.0006	<.0001	0.0001	0.0001; 0.0002	<.0001
<i>Model 2⁴</i>	0.0002	0.0002; 0.0002	0.0003	0.0003; 0.0003	0.0003	0.0003; 0.0003	0.0004	0.0004; 0.0004	0.0006	0.0006; 0.0006	<.0001	0.0001	0.0001; 0.0001	<.0001
Azoxystrobin														
<i>Model 1³</i>	0.0311	0.0298; 0.0323	0.0399	0.0388; 0.0409	0.0447	0.0433; 0.0461	0.0482	0.0471; 0.0493	0.0495	0.0482; 0.0508	<.0001	0.0064	0.0058; 0.0069	<.0001
<i>Model 2⁴</i>	0.0351	0.0338; 0.0364	0.0415	0.0404; 0.0425	0.0446	0.0432; 0.0460	0.0464	0.0453; 0.0475	0.0457	0.0444; 0.0469	<.0001	0.0036	0.0031; 0.0042	<.0001
Boscalid														
<i>Model 1³</i>	0.0767	0.0740; 0.0795	0.1069	0.1045; 0.1093	0.1222	0.1191; 0.1254	0.1323	0.1298; 0.1347	0.1325	0.1297; 0.1353	<.0001	0.0194	0.0182; 0.0206	<.0001
<i>Model 2⁴</i>	0.0909	0.0882; 0.0936	0.1116	0.1093; 0.1139	0.1212	0.1181; 0.1242	0.126	0.1236; 0.1283	0.1208	0.1181; 0.1235	<.0001	0.0104	0.0092; 0.0116	<.0001
Carbendazim														
<i>Model 1³</i>	0.0397	0.0384; 0.0411	0.0459	0.0447; 0.0471	0.0508	0.0492; 0.0523	0.052	0.0508; 0.0532	0.0529	0.0515; 0.0543	<.0001	0.0047	0.0041; 0.0053	<.0001
<i>Model 2⁴</i>	0.0413	0.0399; 0.0426	0.0463	0.0451; 0.0475	0.0506	0.0490; 0.0521	0.0513	0.0502; 0.0525	0.0517	0.0503; 0.0531	<.0001	0.0038	0.0032; 0.0044	<.0001
Chlorpropham														
<i>Model 1³</i>	0.057	0.0553; 0.0588	0.0616	0.0601; 0.0632	0.064	0.0620; 0.0659	0.0669	0.0654; 0.0685	0.0619	0.0601; 0.0636	<.0001	0.0018	0.0011; 0.0026	<.0001
<i>Model 2⁴</i>	0.0653	0.0636; 0.0670	0.065	0.0636; 0.0665	0.0637	0.0618; 0.0656	0.0632	0.0617; 0.0646	0.054	0.0522; 0.0557	<.0001	-0.0039	-0.005; -0.003	<.0001
Chlorpyrifos														
<i>Model 1³</i>	0.0512	0.0497; 0.0528	0.0627	0.0614; 0.0641	0.0698	0.0680; 0.0716	0.0709	0.0695; 0.0723	0.0701	0.0685; 0.0717	<.0001	0.0066	0.0059; 0.0073	<.0001
<i>Model 2⁴</i>	0.0552	0.0537; 0.0568	0.064	0.0627; 0.0653	0.0694	0.0677; 0.0711	0.0692	0.0678; 0.0705	0.0668	0.0652; 0.0684	<.0001	0.0041	0.0034; 0.0048	<.0001
Lambda														
Cyhalothrin														
<i>Model 1³</i>	0.0065	0.0062; 0.0067	0.0092	0.0090; 0.0094	0.0105	0.0102; 0.0108	0.0112	0.0109; 0.0114	0.0113	0.0110; 0.0115	<.0001	0.0016	0.0015; 0.0017	<.0001
<i>Model 2⁴</i>	0.0077	0.0074; 0.0079	0.0096	0.0094; 0.0098	0.0104	0.0102; 0.0107	0.0107	0.0104; 0.0109	0.0103	0.0100; 0.0105	<.0001	0.0009	0.0008; 0.0010	<.0001
Cypermethrin														
<i>Model 1³</i>	0.0616	0.0591; 0.0642	0.0702	0.0680; 0.0724	0.078	0.0751; 0.0809	0.0793	0.0770; 0.0815	0.0804	0.0778; 0.0830	<.0001	0.0069	0.0058; 0.0080	<.0001
<i>Model 2⁴</i>	0.0633	0.0607; 0.0659	0.0705	0.0683; 0.0726	0.0777	0.0748; 0.0805	0.0786	0.0764; 0.0809	0.0794	0.0768; 0.0820	<.0001	0.006	0.0048; 0.0071	<.0001
Cyprodinil														
<i>Model 1³</i>	0.0467	0.0447; 0.0488	0.0663	0.0645; 0.0681	0.0747	0.0724; 0.0770	0.0799	0.0781; 0.0817	0.0789	0.0768; 0.0810	<.0001	0.0112	0.0103; 0.0120	<.0001
<i>Model 2⁴</i>	0.0563	0.0543; 0.0583	0.0694	0.0677; 0.0711	0.0739	0.0717; 0.0762	0.0757	0.0740; 0.0774	0.0711	0.0691; 0.0731	<.0001	0.0051	0.0042; 0.0060	<.0001
Difenoconazole														
<i>Model 1³</i>	0.0115	0.0111; 0.0120	0.0152	0.0149; 0.0156	0.0172	0.0167; 0.0177	0.0189	0.0185; 0.0193	0.0196	0.0192; 0.0201	<.0001	0.0028	0.0026; 0.0030	<.0001
<i>Model 2⁴</i>	0.0131	0.0127; 0.0135	0.0157	0.0154; 0.0161	0.0171	0.0166; 0.0176	0.0182	0.0179; 0.0186	0.0183	0.0179; 0.0188	<.0001	0.0018	0.0016; 0.0020	<.0001
Dimethoate														
Ometoate														
<i>Model 1³</i>	0.0024	0.0023; 0.0025	0.003	0.0029; 0.0031	0.0034	0.0033; 0.0035	0.0035	0.0034; 0.0036	0.0036	0.0035; 0.0037	<.0001	0.0004	0.0004; 0.0004	<.0001
<i>Model 2⁴</i>	0.0027	0.0026; 0.0028	0.0031	0.0030; 0.0032	0.0034	0.0033; 0.0035	0.0034	0.0033; 0.0035	0.0034	0.0033; 0.0035	<.0001	0.0002	0.0002; 0.0003	<.0001

Fenhexamid														
<i>Model 1³</i>	0.0639	0.0605; 0.0673	0.0866	0.0837; 0.0895	0.0984	0.0946; 0.1023	0.1032	0.1003; 0.1062	0.0975	0.0941; 0.1009	<.0001	0.0121	0.0106; 0.0135	<.0001
<i>Model 2⁴</i>	0.0764	0.0730; 0.0797	0.0905	0.0876; 0.0934	0.0974	0.0936; 0.1011	0.0977	0.0948; 0.1006	0.0876	0.0842; 0.0910	<.0001	0.0043	0.0028; 0.0058	<.0001
Glyphosate														
<i>Model 1³</i>	0.0019	0.0017; 0.0020	0.0026	0.0025; 0.0027	0.0034	0.0032; 0.0035	0.0042	0.0041; 0.0043	0.0057	0.0056; 0.0058	<.0001	0.0013	0.0012; 0.0013	<.0001
<i>Model 2⁴</i>	0.0021	0.0020; 0.0022	0.0027	0.0026; 0.0028	0.0034	0.0032; 0.0035	0.0041	0.0040; 0.0042	0.0054	0.0053; 0.0056	<.0001	0.0011	0.0011; 0.0012	<.0001
Imazalil														
<i>Model 1³</i>	0.5605	0.5361; 0.5848	0.7209	0.6999; 0.7419	0.8143	0.7867; 0.8420	0.8317	0.8104; 0.8531	0.8039	0.7793; 0.8285	<.0001	0.0846	0.0741; 0.0951	<.0001
<i>Model 2⁴</i>	0.6315	0.6070; 0.6560	0.7454	0.7246; 0.7662	0.8094	0.7821; 0.8366	0.8003	0.7792; 0.8215	0.7433	0.7186; 0.7679	<.0001	0.0386	0.0278; 0.0495	<.0001
Imidacloprid														
<i>Model 1³</i>	0.0741	0.0721; 0.0760	0.0768	0.0751; 0.0785	0.0822	0.0800; 0.0845	0.0802	0.0785; 0.0819	0.0791	0.0772; 0.0811	<.0001	0.002	0.0012; 0.0029	<.0001
<i>Model 2⁴</i>	0.0773	0.0753; 0.0792	0.0787	0.0771; 0.0804	0.0824	0.0802; 0.0846	0.0788	0.0771; 0.0805	0.075	0.0730; 0.0770	0.15	-0.0005	-0.001; 0.0004	0.25
Iprodione														
<i>Model 1³</i>	0.081	0.0768; 0.0851	0.1227	0.1191; 0.1263	0.143	0.1383; 0.1477	0.152	0.1483; 0.1556	0.1516	0.1474; 0.1558	<.0001	0.0241	0.0223; 0.0259	<.0001
<i>Model 2⁴</i>	0.1008	0.0967; 0.1049	0.1287	0.1252; 0.1322	0.1412	0.1367; 0.1458	0.1432	0.1397; 0.1468	0.136	0.1319; 0.1401	<.0001	0.0117	0.0099; 0.0135	<.0001
Pyrethrins														
<i>Model 1³</i>	0.0017	0.0016; 0.0017	0.0019	0.0018; 0.0019	0.0021	0.0020; 0.0021	0.0023	0.0023; 0.0024	0.0026	0.0026; 0.0027	<.0001	0.0003	0.0003; 0.0004	<.0001
<i>Model 2⁴</i>	0.0018	0.0017; 0.0018	0.0019	0.0019; 0.0020	0.0021	0.0020; 0.0022	0.0023	0.0022; 0.0023	0.0025	0.0025; 0.0026	<.0001	0.0003	0.0003; 0.0003	<.0001
Spinosad														
<i>Model 1³</i>	0.0736	0.0692; 0.0779	0.1105	0.1068; 0.1143	0.1377	0.1328; 0.1426	0.1612	0.1574; 0.1650	0.2214	0.2171; 0.2258	<.0001	0.0507	0.0489; 0.0526	<.0001
<i>Model 2⁴</i>	0.0818	0.0774; 0.0861	0.1124	0.1087; 0.1161	0.1365	0.1317; 0.1414	0.1577	0.1540; 0.1615	0.216	0.2117; 0.2204	<.0001	0.0464	0.0445; 0.0483	<.0001
Tebuconazole														
<i>Model 1³</i>	0.0206	0.0196; 0.0217	0.0302	0.0293; 0.0311	0.0354	0.0342; 0.0366	0.0368	0.0359; 0.0378	0.0365	0.0355; 0.0376	<.0001	0.0054	0.0050; 0.0059	<.0001
<i>Model 2⁴</i>	0.0257	0.0247; 0.0268	0.0318	0.0309; 0.0327	0.035	0.0338; 0.0361	0.0346	0.0337; 0.0355	0.0324	0.0314; 0.0335	<.0001	0.0022	0.0017; 0.0027	<.0001
Thiabendazole														
<i>Model 1³</i>	0.219	0.2112; 0.2268	0.2604	0.2537; 0.2672	0.289	0.2801; 0.2979	0.2912	0.2843; 0.2981	0.2802	0.2723; 0.2881	<.0001	0.0216	0.0182; 0.0250	<.0001
<i>Model 2⁴</i>	0.2412	0.2333; 0.2491	0.2693	0.2626; 0.2760	0.2881	0.2794; 0.2969	0.2813	0.2745; 0.2881	0.2591	0.2512; 0.2670	0.0002	0.0065	0.0030; 0.0100	0.0003

95%CI: 95% confidence interval; MEDI-LITE: Literature-based adherence score to the Mediterranean diet; Q: quintiles.

¹P-values are based on linear contrast tests.

²P-values are calculated by linear regression.

³Model 1: unadjusted.

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

Table 4: Associations between adherence to the Mediterranean diet (MEDI-LITE) and lifestyle and eating practices associated with the Mediterranean lifestyle, n=29,210, 2014, NutriNet-Santé study¹

	Quintiles of level of adherence to the Mediterranean diet					P ²	β	Per SD	
	Q1	Q2	Q3	Q4	Q5			95% CI	P ³
Physical activity, %									
<i>Model 1</i> ⁴						<.0001			
Missing data	11.90	10.68	11.09	10.83	9.44				
Low	26.12	21.71	18.52	16.28	13.12				
Moderate	35.62	35.67	35.73	37.21	37.54				
High	26.36	31.94	34.66	35.68	39.90				
<i>Model 2</i> ⁵						<.0001			
Missing data	11.66	10.29	10.61	10.31	8.91				
Low	24.74	21.21	18.31	16.33	13.17				
Moderate	34.17	35.04	35.59	37.65	38.29				
High	29.43	33.46	35.49	35.71	39.63				
Organic food consumption									
<i>Model 1</i> ⁴	0.18 (0.17; 0.18)	0.24 (0.24; 0.25)	0.28 (0.27; 0.29)	0.33 (0.33; 0.34)	0.45 (0.45; 0.46)	<.0001	0.09	0.09; 0.10	<.0001
<i>Model 2</i> ⁵	0.17 (0.16; 0.17)	0.24 (0.23; 0.24)	0.28 (0.27; 0.29)	0.34 (0.33; 0.34)	0.46 (0.46; 0.47)	<.0001	0.10	0.10; 0.10	<.0001
Consumption of ready-to-use products⁶									
<i>Model 1</i> ⁴	1.27 (1.25; 1.28)	1.21 (1.20; 1.22)	1.19 (1.18; 1.21)	1.17 (1.16; 1.18)	1.09 (1.08; 1.10)	<.0001	-0.06	-0.06; -0.05	<.0001
<i>Model 2</i> ⁵	1.28 (1.27; 1.29)	1.22 (1.21; 1.23)	1.19 (1.18; 1.21)	1.16 (1.15; 1.17)	1.07 (1.06; 1.08)	<.0001	-0.07	-0.08; -0.07	<.0001

95%CI: 95% confidence interval; MEDI-LITE: Literature-based adherence score to the Mediterranean diet; Q: quintiles.

¹Values are means (95%CI) or %, as appropriate.

²P-values are based on Mantel-Haenszel chi-square tests or linear contrast tests, as appropriate.

³P-values are calculated by linear regression.

⁴Model 1: unadjusted.

⁵Model 2: adjusted for age, sex, and daily energy intake.

⁶For consumption of ready-to-use products: N=29,177.