

Title page

Individual characteristics associated with changes in the contribution of plant foods to dietary intake in a French prospective cohort

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Running head: Characteristics associated with changes in plant food intake

Abbreviations:

95% CI: 95% confidence interval

ANOVA: analysis of variance

BMI: body mass index

BMR: Basal Metabolic Rate

CARDIA: Coronary Artery Risk Development in Young Adults

ENNS: Etude Nationale Nutrition Santé

INCA2: Individual and National Consumption Survey 2

PEIPP: percent energy intake provided by plant proteins

SD: standard deviation

SE: standard error

UU: urban unit

WHO: World Health Organization

1 Abstract

2 **Purpose:** Rebalance the contribution of animal- and plant-based foods is needed to achieve
3 sustainable diet. However, little is known concerning individual characteristics that may influence
4 intake of plant-based foods and their changes over time. We aimed to assess changes in the
5 contribution of plant-based foods to dietary intake over time, and their association with individual
6 characteristics.

7 **Methods:** The contribution of plant-based foods was assessed by percent energy intake provided by
8 plant proteins in diet (PEIPP) and a score of adherence to a pro-vegetarian diet, using repeated 24-
9 hours records in 15,615 French adults participating in the NutriNet-Santé cohort study. Associations
10 between baseline individual characteristics and changes in the two indicators over a 4 to 6 year follow-
11 up were assessed using a linear mixed model.

12 **Results:** At baseline, PEIPP and pro-vegetarian score were positively associated with age
13 ($\beta_{65+}=0.80$, 95%CI=[0.71, 0.88], $\beta_{65+}=3.30$, 95%CI=[2.97, 3.64], respectively) and education
14 ($\beta_{\text{postgraduate}}=0.23$, 95%CI=[0.12, 0.34], $\beta_{\text{postgraduate}}=1.19$, 95%CI=[0.75, 1.62]), while they were
15 inversely associated with BMI class ($\beta_{\text{obesity}}=-0.48$, 95%CI=[-0.56, -0.41], $\beta_{\text{obesity}}=-2.31$, 95%CI=[-
16 2.63, -1.98]). Men had higher PEIPP than women ($\beta=0.06$, 95%CI=[0.01, 0.11]). Pro-vegetarian score
17 significantly increased over time ($\beta=0.23$, 95%CI=[0.08, 0.37]). The older the individual at baseline, the
18 greater the decrease in the two indicators during follow-up. Pro-vegetarian score increased during
19 follow-up for obese participants at baseline.

20 **Conclusions:** The contribution of plant-based foods was associated with several socio-demographic
21 and economic characteristics at baseline, whereas change over time was related to age and weight
22 status. Further analysis of individual obstacles and lever to consume plant-based foods is needed.

23 **Keywords:** Plant-based foods, plant proteins, dietary change, sustainable diet, longitudinal analysis,
24 individual characteristics

25 Introduction

26 Consumption of animal-based foods is a major environmental, public health and economic issue [1].
27 Previous studies have highlighted that, compared to production of plant-based foods, production of
28 animal-based foods mobilizes more resources (space, energy, water, etc.) and seems to have a
29 deleterious impact on the environment [2, 3]. However, the health impact of plant-based diet compared
30 with animal-based diet remains an ongoing discussion. Available studies on the health impact of red
31 and processed meat have mostly highlighted that a high consumption of red and processed meat is a
32 notable risk factor for major nutrition-related chronic diseases and for early mortality, compared with
33 low intake or consumption of other meat [4–8]. In contrast, an increasingly number of studies have
34 shown that plant-based diets and diets with lower intake of red and processed meat and higher intake
35 of fruits and vegetables seems to be associated with longer life expectancy and lower risk of chronic
36 disease [9–14]. To improve overall food and nutrition security, and to limit the environmental impact of
37 diet, rebalancing of dietary intake toward plant-based foods in western societies may therefore
38 represent sustainable answers [1, 15].

39 To rebalance the contribution of plant vs. animal foods in the diet, knowledge of the association
40 between consumption of plant- and animal-based foods and individual characteristics is needed.
41 Available studies focused on socio-demographic and economic characteristics associated with intake
42 of specific plant-based foods and, in particular, fruits and vegetables [16–20]. To the best of our
43 knowledge, no study has yet assessed individual determinants of the contribution of plant- and animal-
44 based foods to diet. Understanding changes in dietary intake in recent years based on individual
45 characteristics is essential so as to efficiently promote consumption of plant-based foods [21]. Few
46 available studies have assessed the association between individual characteristics and change in diet
47 over time [22–28]. In the Coronary Artery Risk Development in Young Adults (CARDIA) study
48 conducted among US adults, dietary quality increased over time with age [22]. In contrast, an
49 Australian study showed that younger age at baseline was independently associated with
50 improvement in dietary quality over time [23]. Change in diet quality and fresh vegetable consumption
51 over time was related to gender in Australian and Finnish adults [23, 24]. Regarding socio-economic
52 factors, dietary quality [22, 23, 25] and daily fresh vegetable consumption [24] increased over time in
53 better-educated individuals, subjects belonging to higher occupational and income classes. Regarding

54 lifetime events, a decrease in fruit and vegetable intake at the end of a marriage (divorce, widowhood)
55 [26–28] and an increase upon remarrying were observed [26, 27]. However, no prospective cohort had
56 previously assessed the association between individual characteristics and change in consumption of
57 plant- and animal-based foods in recent years, even though readjustment of such intake has become
58 of greater concern to consumers [29].

59 The aim of the present study was to assess the association between individual characteristics and the
60 contribution of plant-based foods to diet both at baseline and over time, using two complementary
61 indicators. The first indicator that assesses the percent energy intake from plant proteins in diet
62 represents the proportion of plant consumption in the diet from a nutritional point of view while the pro-
63 vegetarian score aims to evaluate the adherence to a vegetarian diet and therefore provides a
64 behavioural point of view of dietary habits [30]. In addition, the first indicator had been previously used
65 in epidemiological studies [31–34], enabling comparison of our results with data from the literature.

66 **Methods**

67 Population

68 Subjects were participants in the NutriNet-Santé study, a large, ongoing, web-based prospective
69 observational cohort launched in France in May 2009. It was implemented in a general population
70 targeting internet-using adult volunteers aged 18 or older. The study was designed to investigate the
71 relationship between nutrition and health, as well as determinants of dietary behaviour and nutritional
72 status. The design and methods of the study have been described previously [35]. For recruitment,
73 initially a vast multimedia campaign (television, radio, national and regional newspapers, posters, and
74 internet) called for volunteers and provided details on the study's specific website (<http://www.etude-nutrinet-sante.fr>). Then, multimedia campaigns were repeated every six months. Further information is
75 maintained on a large number of websites (national institutions, city councils, private firms, web
76 organizations). A billboard advertising campaign is regularly updated via professional channels (e.g.
77 doctors, pharmacists, dentists, business partners, municipalities). Participants were included in the
78 cohort once they had completed a baseline set of questionnaires assessing dietary intake, physical
79 activity, anthropometric measures, lifestyle, socio-economic conditions and health status. As part of
80 their follow-up, participants completed the same set of questionnaires every year. In addition, they
81 were invited monthly to fill out optional complementary questionnaires related to determinants of food
82 behaviour, nutritional and health status.

84 The NutriNet-Santé study was conducted according to guidelines laid down in the Declaration of
85 Helsinki, and all procedures were approved by the Institutional Review Board of the French Institute
86 for Health and Medical Research (IRB Inserm No. 0000388FWA00005831) and the French Data
87 Protection Authority (Commission Nationale Informatique et Libertés No. 908450 and No. 909216).
88 Electronic informed consent was obtained from all participants.

89 Data collection

90 *Dietary assessment*

91 At baseline and each year thereafter, participants were invited to complete three non-consecutive
92 validated web-based 24 hours (24-h) dietary records, randomly assigned over a 2-week period (2

93 weekdays and 1 weekend day) [35]. The dietary record is completed via an interactive interface and is
 94 designed for self-administration on the dedicated website (www.etude-nutrinet-sante.fr) [36]. The
 95 accuracy of this web-based 24-h dietary record was assessed by comparing the record to interviews
 96 by trained dietitians [36] and to 24-h urinary biomarkers [37, 38]. The web-based dietary assessment
 97 method relied on a meal-based approach, recording all foods and beverages (type and quantity)
 98 consumed at breakfast, lunch, dinner and all other eating occasions. First, the participant fills in the
 99 names of all food items eaten. Next, he/she estimates portion sizes for each reported food and
 100 beverage according to standard measurements (e.g., home containers, grams indicated on the
 101 package) or using validated photographs available via the interactive interface. These photographs,
 102 taken from a validated illustrated booklet [39], represent more than 250 foods (corresponding to 1,000
 103 generic foods) served in seven different portion sizes. One dish could pertain to several groups if it
 104 was composed of several components. For each food group, components of composite dishes were
 105 proportionally accounted for, using French recipes validated by food and nutrition professionals.
 106 Values for energy, macronutrients and micronutrients were estimated using published nutrient
 107 databases [40].

108 In the present study, two indicators were used to assess the contribution of plant foods to the diet.
 109 First, a nutritional indicator, the percentage of energy intake without alcohol, provided by plant proteins
 110 was computed as:

$$111 \quad \text{Plant protein, \% of energy} = \frac{\text{plant protein (g)} \times 17 \text{ kJ}}{\text{energy intake without alcohol}} \times 100$$

112 This indicator had been previously used in epidemiological studies [31–34], enabling comparison of
 113 our results with data from the literature. Plant protein intake was positively associated with overall
 114 nutrient adequacy, making a robust marker of health awareness, better compliance to dietary
 115 guidelines and quality of the diet [32, 41]. In addition, the structure of this indicator included the effect
 116 of energy intake, and thus did not require adjustment for this variable.

117 The second indicator, a behavioural indicator, was a score of adherence to a “pro-vegetarian” food
 118 pattern elaborated by Martínez-González *et al.* [30]. Briefly, consumption (in g/day) of seven plant food
 119 groups (vegetables, fruits, legumes, cereals, potatoes, nuts, olive oil) and five animal food groups
 120 (meat and meat products, animal fat for cooking or as a spread, eggs, fish and seafood, dairy

121 products) was computed by adjusting for total energy intake using the residual method [42] separately
122 for men and women. The energy-adjusted estimates were ranked according to their sex-specific
123 quintiles. For this score, plant-derived foods were positively weighted, assigning a value of 1 for the
124 first quintile, 2 for the second quintile, and successively, up to a value of 5 for the fifth quintile. Animal-
125 derived foods were negatively weighted, assigning a value of 5 for the first quintile to 1 for the fifth
126 quintile. The scores were then summed up to obtain a global score ranging from 12 (lowest
127 adherence) to 60 (highest adherence).

128 *Assessment of socio-economic and demographic characteristics*

129 At baseline, self-administered questionnaires were used to collect data on socio-economic and
130 demographic characteristics, including sex, age, size of the urban unit of residence, educational level
131 and household composition. To assess educational level, participants were asked their highest
132 attained diploma. Educational level was recoded into five categories: none or primary education,
133 secondary education, high school graduate or equivalent, undergraduate (corresponding to up to 3
134 years following high school graduation), and post-graduate (more than 3 years after high school
135 graduation). Household composition was classified into three categories: living alone without a child,
136 living with at least one adult and no child, or living with at least one child. Size of the urban unit of
137 residence was categorized into rural, fewer than 20,000 inhabitants, 20,000 to 200,000 inhabitants,
138 more than 200,000 inhabitants and Paris. Height and weight were also self-reported at baseline; body
139 mass index (BMI) was calculated and categorized according to the World Health Organization (WHO)
140 classification for adults [43]: underweight, normal weight, overweight and obesity. Validity of self-
141 reported height and weight has been evaluated by a previous study conducted in the NutriNet-Santé
142 cohort [44]. Self-reported and measured height and weight were compared and showed a sensitivity of
143 88% and a specificity of 99%.

144 Statistical analysis

145 The present analysis focused on participants in the NutriNet-Santé study included between May 2009
146 and April 2010 who had at least 2 sets of 24-h dietary records: at baseline and after 4 years of follow-
147 up. A set was composed of two or three 24-h dietary records. Participants were invited to complete a
148 set every year during the 6 years of follow-up, leading to a maximum of 6 sets of 24-h dietary records

149 per subject (range: 2 to 6 collected sets). Other selection criteria to be included in the analysis sample
150 were: residency in mainland France, not being underreporters of energy intake, and no missing data
151 for individual characteristics at baseline. Self-reported vegetarians and vegans were excluded from
152 this analysis. They are overrepresented in the NutriNet-Santé study cohort, and their inclusion in the
153 analysis sample might have artificially increased the mean scores of vegetable protein consumption.

154 Energy-underreporting participants were identified by the method proposed by Black [45] and
155 excluded. Briefly, basal metabolic rate (BMR) was estimated by Schofield equations [46] according to
156 sex, age, weight and height collected at enrolment in the study. BMR was compared to energy intake,
157 taking into account the physical activity level (a physical activity level of 1.55 was used to identify
158 underreporting subjects) [45].

159 For each sex, weighting was calculated using the iterative proportional fitting procedure according to
160 the 2009 French national census reports on age, occupational categories, educational level, marital
161 status and geographical area of residence [47]. Weighting was accounted for all analyses.

162 Mean percent energy intake provided by plant proteins and mean pro-vegetarian score at baseline
163 were compared by sex, age group, educational level, household composition, size of the urban unit of
164 residence and BMI category, using Student's t-test or analysis of variance (ANOVA) as appropriate,
165 and were presented with their standard error (SE).

166 The database was constituted of repeated yearly measurements of the two dietary indicators for each
167 participant. To assess the evolution of the two indicators over time and their interaction with individual
168 characteristics, linear mixed models were used. They take into account inter-individual variability
169 induced by the change in consumption for each subject, and the intra-subject correlation resulting from
170 repeated measurements of indicators in the same subject [48]. Multivariate linear mixed models,
171 including sex, age, educational level, household composition, size of the urban unit of residence and
172 BMI categories at baseline, were established. Models were also adjusted for household composition at
173 the last follow-up. To select individual characteristics, univariable analysis was conducted and all
174 analyses were significant. A P-value <0.05 was considered statistically significant.

175 Data management and statistical analyses were performed using SAS (version 9.4; SAS Institute, Inc.,
176 Cary, NC, USA).

177 Results

178 Among 33,212 subjects included between May 2009 and April 2010, with at least 2 sets of 24-h
179 dietary records and who were not energy-underreporting subjects, we excluded 499 persons not living
180 in the French metropolitan area, 492 who self-reported being vegetarian and vegan, 268 participants
181 with missing data for variables at baseline (BMI, educational level and size of the UU) and 657
182 participants with missing data for household composition at the last follow-up (Figure 1). We also
183 excluded 15,681 participants who were lost to follow-up after four years, leaving 15,615 participants in
184 the final sample.

185 All subjects had been followed for 4 years, and 51% had been followed for up to 6 years. The mean
186 follow-up was 4.6 years (SD: 0.5 years). In this sample, 29% of the participants had completed all their
187 dietary sets of records every year for 6 years, 36% had 5 sets of records, 21% had 4 sets of records,
188 10% had 3 sets of records and 4% had only 2 sets of records.

189 Comparisons between participants and excluded subjects (17,598 subjects) presented in
190 Supplementary Table 1 showed that included subjects were older (mean 48.4 years (SD: 14.1) vs.
191 41.7 years (SD: 14.1)); the percentage of those not living with children and the prevalence of
192 overweight were higher, while the percentage of those living with children and the obesity prevalence
193 were lower. In addition, the mean percentage of energy intake from plant proteins and the mean pro-
194 vegetarian score were equivalent in both included and excluded subjects (means 5.6% (SD: 1.3) vs.
195 5.5% (SD: 1.4) and 36.1 (SD: 5.1) vs. 35.9 (SD: 5.3), respectively) (Supplementary Table 1).

196 According to raw data, the size of the urban unit of residence of our sample has similar percentage
197 that those reported by the national census while men, young adults, subjects with a low level of
198 education and individuals living with a child were poorly represented in our sample (Table 1).
199 Sociodemographic characteristics were modified by the weighting procedure. Demographic and
200 socioeconomic characteristics were mostly comparable between the weighted sample and the French
201 general population, except for education (Table 1). After weighted, about half of participants in the
202 analysis sample were women (Table 1). Mean age at baseline was 47.8 years (SE: 0.1). In addition,
203 63% of participants had an educational level higher than or equal to high school graduation. More than
204 half of the subjects were living without a child but with at least one adult but only 5% were living alone,

205 and 22% lived in rural areas. Finally, 28% of individuals presented overweight and 10% presented
206 obesity. At baseline, the mean percent energy intake provided by plant proteins (PEIPP) was 5.4%
207 (SD: 0.1, range: 0.9 to 20.1) and the mean pro-vegetarian score was 35.4 (SD: 0.2, range: 16 to 55)
208 (Table 2).

209 The mean PEIPP was higher in older subjects, individuals who lived alone and underweight or normal-
210 weight subjects, compared to young adults, those who lived with at least one child and obese persons
211 respectively (Table 2). The mean pro-vegetarian score was positively associated with age (Table 2).
212 The score was higher in individuals who lived alone or with another adult and in underweight or normal
213 weight subjects compared to those who lived with at least one child, and compared to obese persons.

214 During follow-up, PEIPP decreased slightly (-0.1% (SE: 0.01), $p < 0.01$), while the pro-vegetarian score
215 showed a slight increase (+0.1 (SE: 0.04), $p = 0.02$) over time (Supplementary Table 2). In addition,
216 energy intake without alcohol decreased (-156.2 kJ/day (SE: 16.8), $p < 0.01$) as the mean protein intake
217 (-1.9 g/day (SE: 0.2), $p < 0.01$) and the percent of plant protein in the protein intake (-0.5% (SE: 0.1),
218 $p < 0.01$).

219 Results of the associations between baseline individual characteristics and change over time of PEIPP
220 and the pro-vegetarian score after weighting are presented in Table 3. The pro-vegetarian score
221 significantly increased over time ($\beta = 0.23$, 95% CI = [0.08, 0.37]), while the change in PEIPP was not
222 significant ($\beta = 0.005$, 95% CI = [-0.03, 0.04]). The size of the urban unit of residence was not
223 significantly associated with either of the indicators, either at baseline or during follow-up. Being a man
224 was positively associated with PEIPP, whereas the association between sex and the pro-vegetarian
225 score was not significant. In addition, sex was not significantly associated with change over time of
226 either indicator. PEIPP and the pro-vegetarian score were positively associated with age at baseline.
227 Both indicators declined over time in subjects aged 55 to 64 and over 65. Educational level higher
228 than or equal to an undergraduate degree was positively associated with PEIPP, while an educational
229 level higher than or equal to high school graduation was positively associated with the pro-vegetarian
230 score at baseline. Education was not significantly associated with a change over time of either
231 indicator. Household composition was not significantly associated with the pro-vegetarian score at
232 baseline, but individuals living alone had higher PEIPP than those living with a child. The pro-
233 vegetarian score decreased over time in persons living with at least one adult but without a child

234 compared to those living with a child. Compared to underweight or normal-weight participants,
235 overweight subjects and those with obesity had lower PEIPP and pro-vegetarian score at baseline. In
236 subjects who presented obesity at baseline, pro-vegetarian score significantly increased over time.

237 Discussion

238 To the best of our knowledge, this is the first prospective study on consumption of plant-based foods
239 and its associated characteristics. Also, our study uses of two complementary indicators assessing the
240 contribution of plants to diet from a nutritional and a behavioural point of view, thereby rendering our
241 results more robust.

242 Our findings indicate that the percent energy intake provided by plant proteins, and the pro-vegetarian
243 score, were positively associated with age and education at baseline, while they were inversely
244 associated with weight status. During follow-up, the contribution of plant foods to overall diet
245 decreased in older adults whereas pro-vegetarian score increased only in participants who presented
246 obesity. Thus, very few individual characteristics influenced changes in plant-based food intake over
247 time. This may be due to the slight variation in the contribution of plant-based foods to diet over time
248 across population subgroups. A longer follow-up period might reveal a greater change in food
249 consumption according to individual factors. Another explanation is that, in the context of the recent
250 economic crisis, environmental factors such as food price may more strongly influence consumption of
251 plant-based foods than individual characteristics [49, 50].

252 Men had slightly higher intakes of plant proteins than women whereas previous studies showing lower
253 consumption of plant foods such as fruits and vegetables in men than in women [17, 24, 51]. Further
254 analysis showed that the slightly higher contribution of plant proteins in men in our study may be
255 explained by their equivalent cereals, potatoes and tubers consumption, an important source of plant
256 proteins (Supplementary Table 2).

257 At baseline, the contribution of plant proteins to diet was positively associated with age, in agreement
258 with the literature [17, 18]. This suggests that dietary habits of older adults are more in line with
259 nutritional recommendations than in young adults, including higher consumption of fruits and
260 vegetable, possibly due to a generational effect on dietary patterns and food supply practices. Despite
261 higher intake of plant-based foods, the older the participant at baseline, the more the two indicators
262 decreased over time compared to younger participants at baseline. Food and nutrient intake, including
263 plant-based foods, declined with age [18], possibly due to physiological changes associated with aging
264 such as altered taste and smell, altered digestive capacity and altered dentition and chewing ability,
265 limiting intake of certain foods and reducing dietary diversity [18, 52].

266 In agreement with a multicenter study on protein intake conducted in 10 European countries including
267 France [34], our study showed that education was positively associated with both pro-vegetarian score
268 and PEIPP. Indeed, education is associated with better understanding of the importance of nutritional
269 information messages and the ability to appropriate these in order to generate eating behaviour in line
270 with nutritional recommendations, such as higher consumption of fruits and vegetables and lower
271 intake of animal-based foods [16, 53, 54].

272 Previous studies on the association between the presence of children in the household and intake of
273 fruits and vegetables showed contradictory results [19, 20]. In the present study, at baseline, no
274 significant association was found with the pro-vegetarian score, but individuals who lived alone had
275 higher PEIPP than those living with children. In available studies, for individuals living with children
276 compared to those living alone, overall consumption of meat, seafood and eggs was higher [55, 56],
277 which may explain their lower ratio of plant proteins vs. animal proteins. Results showing the decrease
278 in the pro-vegetarian score over time in persons living with at least one adult but without a child at
279 baseline may be due to additional intrahousehold factors not taken into account in our study, such as
280 psychosocial influences [20, 57].

281 The pro-vegetarian score and the contribution of plant proteins to the diet were lower in subjects who
282 presented overweight and obesity. Our finding is consistent with a multicenter study showing an
283 inverse association between BMI and intake of plant proteins in French women, while a positive
284 association between BMI and intake of animal proteins was found [34]. Our results is also in line with
285 the findings of the prospective cohort Chicago Western Electric Study showing a significant inverse
286 association between higher vegetable protein intake and obesity and a positive association between
287 animal protein intake and obesity in employed men aged 40–55 years [58]. Our result is mainly due to
288 higher consumption of animal foods such as red and processed meats, eggs and dairy products and,
289 to a lesser extent, to lower intake of fruits, cereals and nuts in obese and overweight participants (data
290 not shown). The pro-vegetarian score was higher at baseline and over time for participants who
291 presented obesity compared to underweight or normal-weight participants. Obese subjects increased
292 their intake of plant-based foods such as fruits, legumes and nuts during follow-up, and decreased
293 their intake of animal-based foods (Supplementary Table 2) as a large majority of obese participants in
294 our sample (86%) reported dieting during follow-up. The energy intake decreased during the follow-up

295 as the protein intake but the percent of plant protein in the protein intake increased (Supplementary
296 Table 2). Obese participants at baseline may have changed their dietary intake over time, possibly
297 increasing plant-based food intake.

298 For this analysis, two indicators were chosen among several potential indicators to assess the role of
299 plant foods in the diet. We have chosen the PEIPP rather than the ratio of plant proteins to animal
300 proteins also used in the literature, since our preliminary analyses showed that this indicator reflected
301 the percent energy intake provided by animal proteins. Indeed, when the PEIPP increased, the
302 percent of energy intake provided by animal proteins decreased. Also, an increase in PEIPP was
303 associated with a decrease of the intake of protein: 90.3 g in the first quartile of PEIPP and 83.1 g in
304 the last quartile ($p < 0.01$, Supplementary Table 3). Thereby, an increase in PEIPP not reflects a diet
305 with more protein but it represents an increase of the proportion of plant consumption in the diet from a
306 nutritional point of view. As expected, an increase in the pro-vegetarian score was associated with an
307 increase of plant product intakes but a decrease of the animal product intakes (Supplementary Table
308 4).

309 Interpretation of present results should take into account several limitations. Since the cohort is not
310 random, women and individuals belonging to highly educated groups may be overrepresented. These
311 individuals tend to have lifestyles more in line with nutritional recommendations than the general
312 population [59, 60]. Analyses, however, were weighted according to French population socio-
313 demographic distribution, which allows bias to be limited. Compared to a nationally representative
314 study (Etude Nationale Nutrition Santé (ENNS) 2006-2007), we observed in our study slightly lower
315 total energy and protein intakes at baseline in men (means for energy: 2291.3 kcal (SE: 26.9) vs.
316 2388.7 kcal (SE: 27.7); means for protein: 93.7 g (SE: 1.7) vs. 98.3 g (SE: 1.1), respectively) while
317 intakes were slightly higher in women (means for energy: 1830.4 kcal (SE: 12.2) vs. 1713.7 kcal (SE:
318 14.0); means for protein: 77.6 g (SE: 0.5) vs. 74.1 g (SE: 0.7), respectively) [60]. Compared to another
319 nationally representative study (Individual and National Consumption Survey 2 (INCA2) 2006–2007),
320 total energy intake was also lower in men of our sample (means 2291 vs. 2500 kcal, respectively) but
321 equivalent in women and protein intakes were equivalent for men and women [32]. At baseline, the
322 portion of energy intake from plant proteins was similar compared to the INCA2 (5.4 vs. 4.9%) while
323 the percent of energy intake without alcohol provided by protein in our study was slightly higher in

324 women (17.6 vs. 16.5%, respectively) but similar in men [32]. Difference regarding men in our sample
325 may be due to a bias induced by volunteering: male participants may be more aware and may attach
326 greater importance to nutrition issues and so may make dietary choices more in line with nutritional
327 recommendations than those of the general population. Caution is therefore needed when interpreting
328 and generalizing our results. Differences in dietary intake between gender and education categories
329 are probably wider in the general population, which may explain why there was no significant
330 association with indicators over time. The large size of our sample may have also been a constraint,
331 since significant results were found even when the difference in intake according to categories was
332 slight. However, the large sample size was also a strength, as it enabled a wide diversity of individual
333 characteristics. Validity of self-reported height and weight can be questioned therefore it has been
334 evaluated by a previous study conducted in the NutriNet-Santé cohort, showing that they can be
335 considered as valid enough to be used [44]. The question of accuracy of web-based self-reported data
336 also arises for repeated 24-h dietary records compared to interviews by trained dietitians. However,
337 the validity of our web-based self-reported dietary record tool was tested against 24-h urinary and
338 plasma biomarkers. It showed that the web-based dietary record tool used in the NutriNet-Santé study
339 performs well at estimating protein (correlations with urinary, 0.61 in men, 0.64 in women) and
340 potassium (correlations with urinary, 0.78 in men, 0.42 in women) intakes, and fairly well at estimating
341 fruits and vegetables (correlation with plasma beta-carotene, 0.35 in men and 0.41 in women), fish
342 (correlation with plasma docosahexaenoic acid and eicosapentaenoic acid, 0.51 in men and 0.54 in
343 women), beta-carotene (correlations with plasma, 0.37 in men, 0.38 in women), vitamin C (correlations
344 with plasma, 0.58 in men, 0.32 in women), sodium (correlations with urinary, 0.47 in men, 0.37 in
345 women), and n-3 fatty acids intakes (correlations with plasma, 0.36 in men, 0.38 in women) [37, 38]. In
346 addition, a pilot study comparing our web-based 24-h record tool with dietitian interviews showed
347 strong agreement between the two methods, particularly for plant-based vs. animal-based food intakes
348 [36]. Some participants may belong to the same household and this may modify the results but this
349 information has not been collected. Finally, we did not take into consideration life-events even though
350 previous studies shown that life-events can influence dietary intake [61].

351 **Conclusion**

352 Our findings provide useful information on individual characteristics associated with the contribution of
353 plant-based foods to the overall diet, and changes over time, associated with age, education and BMI.
354 Further studies targeting specific subgroups known to have changed their intake of these foods are
355 needed to understand their motivation to change and identify levers affecting the rebalance of the
356 contribution of plant vs. animal foods in the diet.

357

358 **Conflict of interest:** On behalf of all authors, the corresponding author states that there is no conflict
359 of interest.

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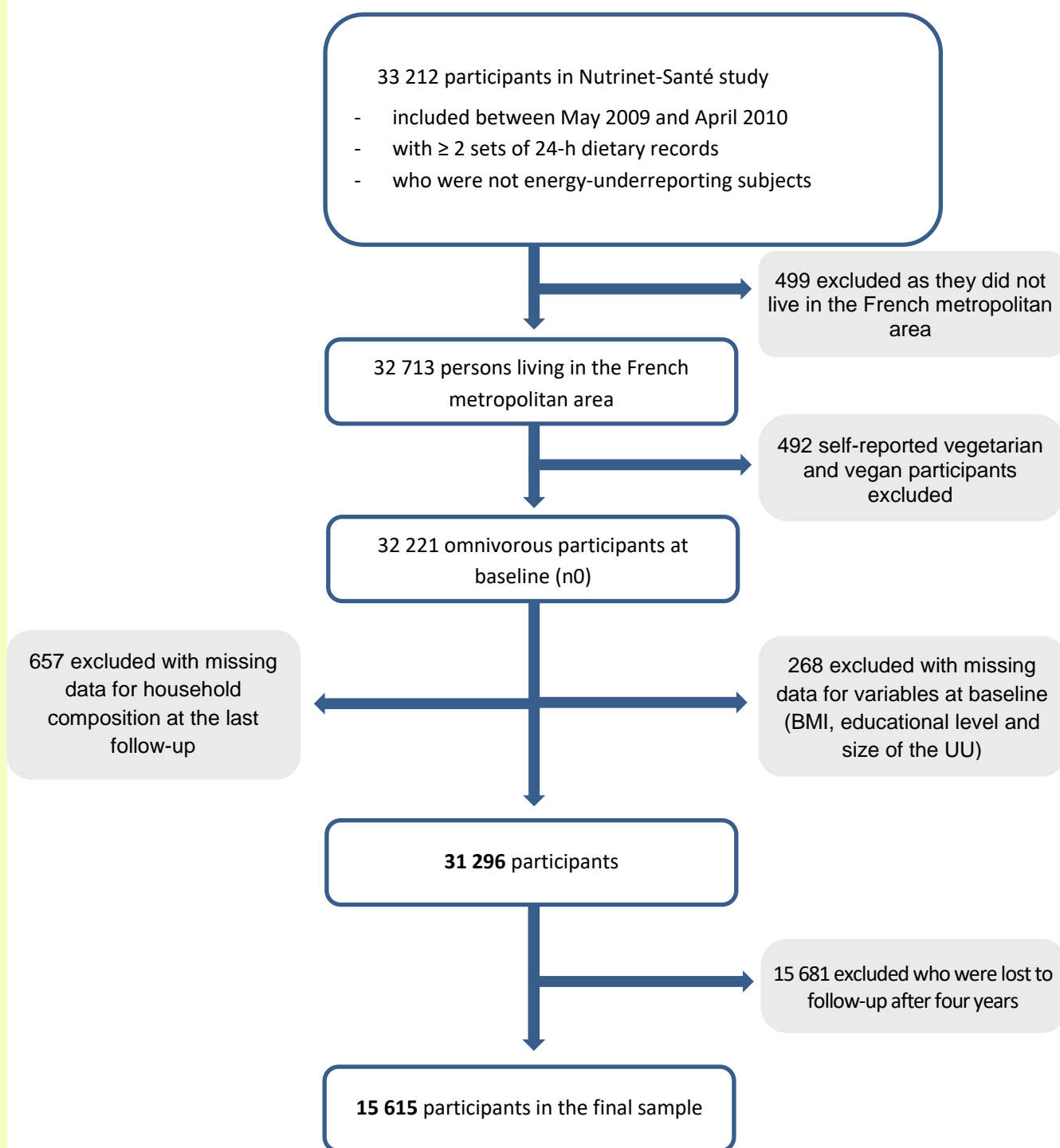


Figure 1. Selection of the analysis sample from the NutriNet-Santé study cohort.

Table 1. Characteristics of the sample ($n = 15,615$).

	<i>Raw data</i>		<i>Weighted data*</i>	<i>Census estimates**</i>
	<i>n</i>	%	%	%
Sex				
Women	11427	73.2	52.4	52.4
Men	4188	26.8	47.6	47.6
Age class				
18-29 Years	1913	12.3	16.0	19.2
30-49 Years	5606	35.9	36.5	34.9
50-64 Years	6515	41.7	25.9	24.4
≥ 65 Years	1581	10.1	21.6	21.6
Educational level				
None or primary	441	2.8	11.4	25.3
Secondary	2038	13.1	26.0	34.3
High school graduate	3058	19.6	40.4	15.9
Undergraduate	4682	30.0	10.3	11.8
Postgraduate	5396	34.6	11.9	12.7
Household composition				
Living alone	2656	17.0	5.1	14.8
Living with at least one adult, but without a child	8487	54.4	58.3	27.3
Living with a child	4472	28.6	36.6	57.9
Size of the urban unit of residence				
Rural	3420	21.9	22.4	25.8
< 20,000 inhabitants	2535	16.2	18.0	16.7
20,000 - 200,000 inhabitants	2727	17.5	18.6	18.5
> 200,000 inhabitants	4123	26.4	24.9	22.5
Paris	2810	18.0	16.0	16.5
BMI class				
Underweight or normal weight	11020	70.6	62.1	50.7***
Overweight	3466	22.2	27.7	32.4***
Obesity	1129	7.2	10.3	16.9***

* Weighting accounted for each gender and social and demographic characteristics compared to the national census (age, occupational categories, area of residence, marital status and educational level).

** 2009 national estimates for individuals aged ≥18 years in metropolitan France

*** prevalence from a nationally representative study (Etude Nationale Nutrition Santé (ENNS) 2006-2007)

Table 2. Comparison of the percent energy intake* provided by plant proteins and the pro-vegetarian score according to individual characteristics at baseline in French adults participating in the NutriNet-Santé cohort ($n = 15,615$)**.

	Percent energy intake provided by plant proteins***		Pro-vegetarian score†	
	Mean \pm SE	p-value	Mean \pm SE	p-value
Total sample	5.4 \pm 0.1		35.4 \pm 0.2	
Sex		0.69		0.66
Women	5,4 \pm 0.03		35.5 \pm 0.2	
Men	5,4 \pm 0.1		35.3 \pm 0.4	
Age class		< 0.0001		< 0.0001
18-29 Years	4,9 \pm 0,1		34.1 \pm 1.0	
30-49 Years	5,3 \pm 0,2		34.8 \pm 0.4	
50-64 Years	5,6 \pm 0,1		35.6 \pm 0.3	
\geq 65 Years	5,8 \pm 0,1		37.2 \pm 0.2	
Educational level		0.03		0.09
None or primary	5,3 \pm 0,4		34.4 \pm 0.9	
Secondary	5,6 \pm 0,1		35.7 \pm 0.3	
High school graduate	5,3 \pm 0,1		35.4 \pm 0.5	
Undergraduate	5,3 \pm 0,04		35.4 \pm 0.2	
Postgraduate	5,5 \pm 0,03		36.0 \pm 0.1	
Household composition		0.03		< 0.0001
Living alone	5,6 \pm 0,1		36.2 \pm 0.4	
Living with at least one adult, but without a child	5,5 \pm 0,1		36.1 \pm 0.3	
Living with a child	5,1 \pm 0,1		34.3 \pm 0.4	
Size of urban unit of residence		0.19		0.08
Rural	5,3 \pm 0,1		35.0 \pm 0.3	
< 20,000 inhabitants	5,7 \pm 0,2		35.1 \pm 0.3	
20,000 – 200,000 inhabitants	5,3 \pm 0,1		35.9 \pm 0.7	
> 200,000 inhabitants	5,3 \pm 0,2		35.3 \pm 0.6	
Paris	5,3 \pm 0,1		36.0 \pm 0.2	
BMI class		0.02		0.0001
Underweight or normal weight	5,4 \pm 0,1		35.8 \pm 0.3	
Overweight	5,5 \pm 0,1		35.3 \pm 0.3	
Obesity	5,1 \pm 0,1		33.5 \pm 0.5	

* Energy intake without alcohol.

** Sex-specific data weighted for age, occupational categories, area of residence, marital status and educational level, using 2009 national census. Student's t-test or analysis of variance (ANOVA) as appropriate.

*** Percentage of daily energy intake without alcohol provided by plant proteins.

† Score of adherence to a pro-vegetarian food pattern elaborated by Martínez-González *et al.* Energy-adjusted estimates of consumption of seven plant and five animal food groups were ranked according to sex-specific quintiles. The quintiles were scored from 1 to 5 and these scores were summed up to obtain an overall score ranging from 12 (lowest adherence) to 60 (highest adherence).

Table 3. Multivariate linear mixed analysis* showing associations between baseline individual characteristics, changes in percent energy intake** provided by plant proteins and the pro-vegetarian score up to 6 years in French adults participating in the NutriNet-Santé cohort ($n = 15,615$)***.

	Percent energy intake from plant proteins †		Pro-vegetarian score ‡	
	β (95% CI)	p-value	β (95% CI)	p-value
Time	0.005 (-0.03, 0.04)	0.78	0.23 (0.08, 0.37)	0.002
Sex				
Men	0.06 (0.01, 0.11)	0.01	-0.07 (-0.26, 0.12)	0.49
Men*time	0.001 (-0.01, 0.01)	0.92	-0.04 (-0.10, 0.01)	0.10
Age class				
18-29 years	Reference		Reference	
30-49 years	0.46 (0.39, 0.53)	< 0.0001	1.57 (1.28, 1.86)	< 0.0001
30-49 years*time	-0.01 (-0.03, 0.004)	0.13	-0.04 (-0.13, 0.04)	0.30
50-64 years	0.68 (0.61, 0.75)	< 0.0001	2.66 (2.37, 2.94)	< 0.0001
50-64 years*time	-0.04 (-0.06, -0.02)	< 0.0001	-0.09 (-0.17, -0.01)	0.04
≥ 65 years	0.80 (0.71, 0.88)	< 0.0001	3.30 (2.97, 3.64)	< 0.0001
≥ 65 years*time	-0.05 (-0.07, -0.03)	< 0.0001	-0.13 (-0.22, -0.04)	0.01
Educational level				
None or primary	Reference		Reference	
Secondary	-0.001 (-0.11, 0.11)	0.99	-0.01 (-0.44, 0.43)	0.98
Secondary*time	0.01 (-0.02, 0.04)	0.44	-0.05 (-0.16, 0.07)	0.43
High School graduate	0.09 (-0.02, 0.19)	0.12	0.47 (0.05, 0.89)	0.03
High School graduate*time	0.003 (-0.02, 0.03)	0.80	-0.07 (-0.18, 0.03)	0.19
Undergraduate	0.12 (0.01, 0.23)	0.03	0.65 (0.22, 1.08)	0.003
Undergraduate*time	0.01 (-0.01, 0.04)	0.38	-0.08 (-0.19, 0.04)	0.18
Postgraduate	0.23 (0.12, 0.34)	< 0.0001	1.19 (0.75, 1.62)	< 0.0001
Postgraduate*time	-0.01 (-0.03, 0.02)	0.64	-0.07 (-0.18, 0.04)	0.22
Household composition				
Living with a child	Reference		Reference	
Living alone	0.11 (0.02, 0.21)	0.02	0.05 (-0.34, 0.43)	0.82
Living alone*time	0.0004 (-0.02, 0.02)	0.97	-0.05 (-0.15, 0.05)	0.31
Living with at least one adult, but without a child	0.03 (-0.03, 0.09)	0.31	0.25 (-0.01, 0.51)	0.05
Living with at least one adult, but without a child *time	-0.002 (-0.02, 0.01)	0.84	-0.07 (-0.14, -0.01)	0.03
Size of urban unit of residence				
20,000 – 200,000 inhabitants	Reference		Reference	
Rural	-0.04 (-0.1, 0.03)	0.25	-0.19 (-0.46, 0.08)	0.16
Rural*time	-0.005 (-0.02, 0.01)	0.60	-0.01 (-0.09, 0.06)	0.79
< 20,000 inhabitants	-0.02 (-0.09, 0.05)	0.53	-0.15 (-0.44, 0.14)	0.31
< 20,000 inhabitants*time	-0.001 (-0.02, 0.02)	0.95	0.05 (-0.03, 0.13)	0.19
> 200,000 inhabitants	-0.03 (-0.09, 0.03)	0.34	0.15 (-0.12, 0.41)	0.27
> 200,000 inhabitants*time	-0.003 (-0.02, 0.01)	0.69	0.01 (-0.06, 0.08)	0.80

Paris	-0.01 (-0.07, 0.06)	0.88	0.07 (-0.22, 0.35)	0.64
Paris*time	-0.01 (-0.03, 0.01)	0.37	-0.03 (-0.11, 0.05)	0.53
BMI class				
Underweight or normal weight	Reference		Reference	
Overweight	-0.28 (-0.33, -0.23)	< 0.0001	-1.21 (-1.42, -1.01)	< 0.0001
Overweight*time	0.004 (-0.01, 0.02)	0.53	0.01 (-0.05, 0.06)	0.80
Obesity	-0.48 (-0.56, -0.41)	< 0.0001	-2.31 (-2.63, -1.98)	< 0.0001
Obesity*time	0.02 (-0.005, 0.04)	0.14	0.09 (0.004, 0.18)	0.04

* Adjusted for household composition at the last follow-up.

** Energy intake without alcohol.

*** Sex-specific data weighted for age, occupational categories, area of residence, marital status and educational level, using 2009 national census

† Percentage of daily energy intake without alcohol provided by plant proteins.

‡ Score of adherence to a pro-vegetarian food pattern elaborated by Martínez-González *et al.* Energy-adjusted estimates of consumption of seven plant and five animal food groups were ranked according to sex-specific quintiles. The quintiles were scored from 1 to 5 and these scores were summed up to obtain an overall score ranging from 12 (lowest adherence) to 60 (highest adherence).