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Dietary Pattern Trajectories in French Adults of the NutriNet-Santé Cohort Over Time

(2014-2022): Role of Socioeconomic Factors.

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A full list of TRANSFood consortium is provided at the end of the manuscript

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Registration of Clinical Trial

Trial registration number: NCT03335644

URL of registration: <https://clinicaltrials.gov/study/NCT03335644?id=NCT03335644&rank=1>

Data Share Statement

Analytic code will be made available upon request pending. Researchers from public institutions can submit a collaboration request including information on the institution and a brief description of the project to collaboration@etude-nutrinet-sante.fr. All requests will be reviewed by the steering committee of the NutriNet-Santé study. If the collaboration is accepted, a data access agreement will be necessary and appropriate authorizations from the competent administrative authorities may be needed. In accordance with existing regulations, no personal data will be accessible.

Running title: Dietary pattern evolutions and role of socioeconomic factors

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Supplemental material: 1 method ,5 tables, 1 figure

Keywords: longitudinal dietary changes, gender-specific approach, socioeconomic factors, diet quality.

Abstract

1 While dietary transitions towards more plant-based diets are urgently needed, few studies have
2 investigated current diet trajectories, based on observed longitudinal data. This study investigated
3 current dietary transitions of French adults over an 8 years period (2014-2022), while assessing the
4 diet quality and the role of diverse socio-economic factors.

5 Consumption data from 17,187 NutriNet-Santé cohort participants weighted for the French Census
6 were collected using a food frequency questionnaire in 2014, 2018, and 2022. Adopting a gender-
7 specific approach, consumption changes in 23 food groups were assessed over time. The diet quality
8 was evaluated using the Comprehensive Diet Quality Index (cDQI) score, categorizing foods into
9 "healthy" and "unhealthy". The socioeconomic analysis targeted four food groups (red meat
10 (including fresh beef, pork, offal, and lamb), processed meat (e.g. sausages, ham, and bacon),
11 legumes, and wholegrain products), strongly linked to mortality risk and recognized as significant
12 markers of the sustainable diet transition. All analyses were conducted using multi-adjusted mixed-
13 effects models.

14 Consumption of some healthy plant-based foods (nuts +59 %, legumes +22%, wholegrain products
15 +7%) significantly increased over time; while consumption of some unhealthy foods (red meat -19%,
16 refined cereals -18%, sweetened drinks -15%) decreased. Conversely, consumption of prepared and
17 mixed dishes (+16%), and processed meat (+35%) increased. These changes differed in magnitude
18 between genders and translated into an improved diet quality score (cDQI). Occupational status was
19 linked to longitudinal changes in food consumption, showing increased consumption of plant-based
20 foods among students and higher socio-professional categories.

21 Our findings provide accurate data on trends and factors for targeted initiatives, guiding strategic
22 interventions for a sustainable dietary transition.

Abbreviations:

aDQI: Animal-based Diet Quality Index
C.U. : Consumption Unit
cDQI: Comprehensive Diet Quality Index

COP: Conference of the Parties to the United Nations Framework Convention on Climate Change

GBD: Global Burden of Disease

GHG : Greenhouse Gas

IPCC: Intergovernmental Panel on Climate Change

NDCs: Nationally Determined Contributions

Org-FFQ: Organic Food Frequency Questionnaire

pDQI: Plant-based Diet Quality Index

PMD: Prepared and Mixed Dishes

SD: standard deviation

SDGs: Sustainable Development Goals

SSFF: Salty and Sweetened Fatty Foods

TEI: Total Energy Intake

23 **Highlights**

- 24 • Consumption of some healthy plant-based foods (legumes +22%, nuts +59 %, whole-grain
25 products +7%) significantly increased over time (2014-2022); while consumption of some
26 unhealthy foods (red meat -19%, refined cereals -18%, sweet drinks -15%) decreased.
- 27 • Consumption of prepared and mixed dishes (+16%) and processed meat (+35%) increased
28 during the study period.
- 29 • Diet quality (cDQI score) increased over time.
- 30 • Differences were observed between women and men in baseline consumption and in the
31 magnitude of changes over time.
- 32 • Occupational status was linked to longitudinal changes in food consumption.
- 33 • Increased consumption of plant-based foods was observed among students and higher socio-
34 professional categories.

35 **Introduction**

36 The rate of climate change is accelerating at an alarming pace, outstripping current mitigation efforts
37 and intensifying the need for swift and effective measures. In 2023, Europe experienced one of its
38 hottest years on record (1), underscoring the troubling reality that some planetary boundaries have
39 been irreversibly crossed (2–4). Additionally, food systems, which account for nearly one-third of
40 global greenhouse gas (GHG) emissions (5), are often overlooked in climate policies (6). Although
41 some Nationally Determined Contributions (NDCs) mention this sector, they focus on production,
42 neglecting key factors like food waste and consumption habits, which are significant contributors to
43 emissions (6). Therefore, adopting a comprehensive approach to food systems to improve climate
44 strategies is crucial, addressing all stages from production to sustainable consumption. In line with
45 this, the 28th Conference of the Parties to the United Nations Framework Convention on Climate
46 Change (COP28) Declaration on Food and Agriculture emphasizes the need for stronger collaboration
47 between key ministries (agriculture, climate, energy, environment, finance, and health) (7) to meet
48 the Sustainable Development Goals by 2030 (8). Moreover, policymakers should consider local
49 consumption patterns and cultural contexts to ensure that climate measures are both realistic and
50 effective. In this context, consumer habits are crucial for effective transition strategies, as dietary
51 shifts are increasingly necessary to mitigate climate change (9,10), as noted in the latest
52 Intergovernmental Panel on Climate Change (IPCC) report (11). Reducing animal-based food
53 consumption, which generates twice the emissions of plant-based alternatives (12), is critical in
54 lowering environmental impacts. For example, replacing red meat with poultry (13) or increasing the
55 proportion of plant-based proteins in the diet (14) lessens the contribution to global warming.

56 A shift towards more plant-based diets is already observed in WHO member countries (15), despite
57 the relatively limited adoption of vegetarian and vegan diets (16). Between 2009 and 2019, notable
58 dietary changes were documented, particularly in France, where red meat consumption declined in
59 favor of poultry and processed meats, predominantly among individuals aged 65 and older. In
60 contrast, those over 50 demonstrated an increased consumption of fruits and vegetables (17).

61 Nevertheless, these dietary shifts remain polarized, with some populations adopting more
62 sustainable and health-promoting diets, while others continue to follow less favorable eating
63 patterns. This polarization can largely be attributed to socio-economic factors, as described in the
64 Social Determinants of Health (SDH) Framework, which emphasizes the distinction between various
65 levels of causality (18), and the Nutrition Health Disparities Framework (NHDF) (19), a recent
66 adaptation of the SDH specifically focused on nutrition. For example, income levels are crucial in
67 determining access to high-quality foods, contributing to nutritional inequalities (20). According to
68 Bennett's law (21), higher income facilitates a more diverse diet that includes animal proteins, while
69 lower income is associated with increased carbohydrate consumption and a reduction in protein
70 intake. Moreover, foods of lower nutritional value tend to be more affordable per calorie, making
71 them more accessible to lower socio-economic groups (20). Favorable dietary practices, such as a
72 higher consumption of fruits and vegetables, are often associated with a higher socio-economic
73 status, particularly in relation to educational attainment (22).

74 Despite advancements in the study of dietary behaviors, a substantial gap remains in understanding
75 the relationships between these individual behaviors and socioeconomic status. This deficiency is
76 often due to the complex interplay of various internal and external factors influencing food choices
77 (19). In this context, our study aims to improve this understanding by characterizing the changes in
78 individual dietary consumption in France over the last decade while assessing diet quality.
79 Furthermore, we will explore the associations between these dietary changes in the four
80 sustainability-relevant food groups and individuals' socioeconomic status to better elucidate the
81 connections between these two dimensions. Thus, the main objective of this analysis is to provide
82 accurate data on the ongoing trends and the factors associated with these changes, intending to
83 develop targeted initiatives tailored to specific food groups and subgroups within the population.
84 This approach seeks to inform strategic and customized interventions that promote a sustainable
85 dietary transition among the population.

86 **Methods and Data**

87 ***Study population***

88 The current study used longitudinal observational data from 2014 to 2022, using a sub-sample of the
89 NutriNet-Santé study. Initiated in May 2009, the NutriNet-Santé study is an online-based cohort
90 aimed at examining the factors influencing diets, nutritional status, physical activity, and their
91 relationships to health outcomes (23). The study involves the adult participants residing in France
92 who have internet access, recruited on a voluntary basis. Participants are required to complete
93 annual or biannual questionnaires covering socioeconomic status, lifestyle, anthropometry, dietary,
94 and physical activity habits (24). Additional questionnaires are periodically administered. Gender,
95 occupational status, income, place of residence, physical activity levels, and smoking habits are all
96 self-reported using validated questionnaires (24).

97 The NutriNet-Santé study complies with the principles outlined in the Helsinki Declaration and has
98 received validation from both the INSERM Ethical Evaluation Committee (CEEI) (no.
99 0000388FWA00005831) and the National Committee for Information Technology and Freedom
100 (CNIL) (nos. 908450 and 909216). The study is also registered on ClinicalTrials.gov (NCT03335644).

101 ***Sociodemographic data***

102 The self-reported individual characteristics, including gender, age, educational level (primary,
103 secondary, post-secondary), employment status (unemployed, managerial staff, employee or manual
104 laborer, self-employed or farmer, intermediate profession, student, retired), and monthly household
105 income per consumption unit (c.u.) considering household size and the age of its members (<1200;
106 1200-1800; 1800-2700; >2700 in euros per c.u. per month) (25) were collected at the baseline year
107 2014.

108 ***Assessment of food group consumption***

109 Food consumption data were collected in 2014, 2018, and 2022, through the use of an Organic Food
110 Frequency Questionnaire (Org-FFQ) encompassing a total of 264 organic and conventional food
111 items, as described elsewhere (26). For the current study, a classification into 23 food groups has

112 been established based on their nutritional value and contents, as follows: red meat, poultry,
113 processed meat, fish, eggs, dairy products (excluding milk), milk, animal substitutes, vegetables,
114 fruits, fruit juice, legumes, wholegrain products, nuts, potatoes, refined cereals, prepared and mixed
115 dishes (PMD) (including sandwich, prepared foods such as pizza, hamburger, ravioli, panini, salted
116 pancake), salty and sweetened fatty foods (SSFF) (including croissants, pastries, chocolate, biscuits,
117 milky dessert, ice cream, honey and marmalade, cakes, chips, salted oilseeds, salted biscuits),
118 sweetened drinks, hot drinks, alcohol, butter, and plant-based fat. Total daily energy intake (TEI) was
119 calculated using the food composition table designed for the NutriNet-Santé study (27).

120 ***Diet quality data***

121 Three dietary indexes were calculated for assessing the trend towards a healthy plant-based diet.
122 The **cDQI** (Comprehensive Diet Quality Index) is designed to assess overall diet quality by evaluating
123 their plant and animal components (28).

124 The **pDQI** (Plant-based Diet Quality Index) emphasizes on the quality of plant-based foods, dividing
125 into two categories: healthy foods (including wholegrain products, fruits, vegetables excluding
126 potatoes, nuts, seeds and legumes, vegetable oils, coffee, and tea) and foods to be consumed with
127 moderation (such as refined grains, fruit juices, potatoes, sweetened beverages, and sugary foods).

128 Similarly, the **aDQI** (Animal-based Diet Quality Index) evaluates the role of dietary quality of animal-
129 origin foods. This index comprises two groups of items: healthy foods (such as fish, seafood, dairy
130 products, and poultry) and items to be restricted (including red meat, processed meat, and eggs).
131 Each food item is assigned a score ranging from 0 to 5 based on its alignment with the reference
132 consumption. Consequently, the ultimate pDQI scores range from 0 to 55, and the aDQI scores range
133 from 0 to 30. The comprehensive cDQI score is derived by summing the pDQI and aDQI scores, range
134 from 0 to 85.

135 ***Statistical Analysis***

136 This study included 17,187 participants who provided Org-FFQ data on food consumption during at
137 least two collection periods (2014, 2018, and/or 2022). From an initial eligible population of 29,195
138 individuals who completed the FFQ in 2014, we selected those with a follow-up in either 2018 or
139 2022 to ensure longitudinal tracking. This approach accommodates missing data in mixed-effects
140 models, allowing for the modeling of consumption trajectories with at least two follow-up points.
141 Individuals who completed the FFQ in 2018 and/or 2022 but did not participate in 2014 were
142 excluded from the analysis. The sample selection process is depicted in **Supplemental Figure 1**.
143 These participants had no missing information regarding sociodemographic factors (except for the
144 non-mandatory monthly income question) and were not living overseas to permit the computation
145 of a weighting procedure described below. Individuals classified as either underreporting or
146 overreporting their energy intake, as detailed in a previous publication (26) , were excluded.
147 In order to correct the low generalizability of the findings from the sample of volunteers in the
148 NutriNet-Santé cohort, the sample was corrected by weighting using the iterative proportional fitting
149 procedure according to 2009 national census reports (29) on age, occupational category, educational
150 level, area of residence, presence of children (<18 years) and marital status.
151 This method aims to enhance the representativeness of our sample within the French population.
152 Consequently, a weighting factor was computed for each individual, reflecting the probability of their
153 inclusion in a representative sample (29).
154 Study population was described using mean (SD) or n % for continuous and categorical variables,
155 respectively. The Pearson's Chi-square test was used for categorical variables, while the ANOVA test
156 was used for continuous variables.
157 To estimate changes in consumption of 23 food groups over time, mixed-effects models for repeated
158 measurements were employed, adjusted for gender, age and total energy intake. Further details are
159 outlined in **Supplemental Method 1**.
160 We secondly aimed to examine socioeconomic factors associated with the consumption of four food
161 groups, namely red meat, processed meats, legumes, and wholegrain products, along with their

162 longitudinal change. These food groups are strongly associated with mortality risk, both positively
163 and negatively, based on data from the Global Burden of Disease (GBD) (30), and recognized as
164 significant markers of the transition toward sustainable diets (31–34). To achieve this, mixed-effects
165 models similar to those used earlier were used, incorporating the relevant covariates, as described in
166 **Supplemental Method 1.**

167 This analysis was conducted on a sample of 16,239 individuals, for whom income data were available.
168 Furthermore, we computed the percentage variations relative to each food group, examining
169 changes over time, across genders and socioeconomic factors using the least squares means of
170 adjusted consumptions.

171 To assess the overall change of the quality of dietary patterns over time, we computed the cDQI
172 indicator (28), along with its two components, the aDQI and the pDQI reflecting DQI of animal and
173 plant-based foods respectively. This approach allows for a meaningful classification of foods into
174 "healthy" and "unhealthy" categories. Similar mixed-effects models as those employed earlier were
175 utilized and detailed in **Supplemental Method 1.**

176 **Results**

177 ***Sample characteristics***

178 After sample weighting, the gender ratio was balanced between men (48%) and women (52%), with
179 an average age of 48 (SD=16) years old (**Table 1**). A detailed comparison of the differences between
180 respondents and non-respondents is provided in **Supplemental Table 1.**

181 ***Overall dietary change over 8 year***

182 Significant changes in consumption patterns were observed over the past 8 years among the whole
183 population for the majority of the 23 food groups examined (**Figure 1** and **Supplemental Table 2**).
184 The significant declines ($p < 0.01$) (**Supplemental Table 3**) were in consumption of fruit juices (-40%),
185 red meat (-19%), refined cereals (-18%), sweetened drinks (-15%), poultry (-12%), milk (-12%), alcohol
186 (-12%) and fish (-6%). Conversely, food groups with the most noticeable increases ($p < 0.01$) included

187 butter (+100%), nuts (+59%), eggs (+39%), processed meat (+35%), animal substitutes (+22%),
188 legumes (+22%), prepared and mixed dishes (+16%) and wholegrain products (+7%).

189 Consumption of vegetables (+4%), fruits (+4%) and salty and sweetened fatty Foods (SSFF) (+3%)
190 slightly increased over time ($p<0.01$), while consumption levels of fruits (+2%), hot drinks (+2%), and
191 potatoes (+1%) remained relatively stable ($p<0.01$). However, the variations observed for dairy
192 products ($p\approx 0.85$) and plant-based fats ($p\approx 0.36$) over time were not statistically significant.

193 Consistently with the increase in consumption of healthy foods, a growing cDQI score over time was
194 observed ($p<0.01$). The same was true for animal (aDQI) and plant (pDQI) components of the diet. It
195 should be noted that these scores were higher for women compared with men (**Figure 1**).

196 ***Gender-specific dietary change***

197 Baseline consumption levels (2014) varied depending on gender (**Figure 1** and **Supplemental Tables 2**
198 **and 3**). Women had higher consumption levels of healthy food groups than men ($p<0.01$), including
199 nuts (+85% compared to men), fruits (+40%), plant-based fats (+34%), vegetables (+25%), wholegrain
200 products (+10%). On the other hand, men had higher consumption levels of red meat (+23%
201 compared to women; $p<0.01$), energy-dense foods (potatoes (+35%; $p<0.01$) and refined cereals
202 (+27%; $p<0.01$)), prepared and mixed dishes (+15%; $p<0.01$), salty and sweet fatty products (+7%;
203 $p<0.01$)), and alcohol (+119%; $p<0.01$).

204 Moreover, differences in food groups' consumption over time were observed between genders
205 (**Figure 1** and **Supplemental Tables 2 and 3**). A widening discrepancy in the consumption of
206 processed meat was noted, particularly with a notable increase among men (the gap went from +7%
207 in 2014 to +30% in 2022, with a higher consumption among men; $p<0.01$). Additionally, a more
208 pronounced decline in sweetened drink consumption was observed among women (the gap went
209 from +16% in 2014 to +38% in 2022, with a higher consumption among men; $p\approx 0.01$).

210 ***Socioeconomic factors linked to the consumption of food groups highly associated with*** 211 ***mortality risk***

212 Socioeconomic factors, namely income, education, and occupational status, were associated with the
213 consumption of the food groups examined in this study to varying degrees (**Figure 2** and
214 **Supplemental Tables 4 and 5**). All results were estimated with respect to the reference categories,
215 including “highest income (>€2700/C.U./month)” for income, “retired” for occupational status, and
216 “post-secondary” for educational level.

217 Income and education level were primary determinants of baseline consumption patterns, while
218 occupational status played a significant role in influencing changes over time. Participants with
219 higher education levels and lower incomes tended to consume more plant-based foods at the outset,
220 and this trend intensified over time, particularly among students and individuals in higher socio-
221 professional categories. Specifically, legume consumption at baseline was 22% higher among
222 individuals with the lowest incomes ($p<0.01$), while wholegrain products consumption was 6% higher
223 among those with moderate incomes ($p\approx 0.02$). Conversely, individuals with the lowest education
224 levels exhibited the lowest baseline consumption of wholegrain products, with a 13% reduction in
225 consumption ($p<0.01$).

226 Over the period from 2014 to 2022, the increase in legume consumption was notably more
227 pronounced among participants in intermediate professions, showing a rise of 36% ($p<0.01$). For
228 wholegrain products, the greatest increases were observed among students (+29%; $p<0.01$), those in
229 intermediate professions (+23%; $p<0.01$), individuals in intellectual or managerial roles (+14%;
230 $p<0.01$), and employees or manual workers (+20%; $p<0.01$).

231 Conversely, participants with lower education levels consumed more animal-based foods. More
232 specifically, at baseline, red meat consumption was 14% higher ($p < 0.01$) among individuals with the
233 lowest education levels, while processed meat consumption was also highest in this group, with an
234 8% greater consumption ($p < 0.01$). In contrast, individuals with the lowest incomes consumed 11%
235 less red meat ($p < 0.01$), whereas processed meat consumption was 6% higher among those with
236 moderate incomes ($p < 0.01$). Over time, the decline in red meat consumption from 2014 to 2022
237 was more pronounced among participants in intermediate professions (-20%; $p\approx 0.03$), intellectual or

238 managerial professions (-21%; $p < 0.01$), and high-income earners (-20%). The gap in red meat
239 consumption between the lowest and highest income groups narrowed over this period, decreasing
240 from an 11% difference in 2014 to 8% in 2022 ($p \approx 0.04$). For processed meat, the increase over time
241 was more significant among those in intermediate professions (+32%; $p \approx 0.01$), intellectual or
242 managerial professions (+34%; $p < 0.01$), and students (+20%; $p \approx 0.01$).

243 **Discussion**

244 ***Towards healthier food consumption***

245 Over the study period (2014-2022), we noted changes for most of the studied food groups
246 consumption. A notable trend was the increased consumption of healthy plant-based foods
247 (legumes, nuts and wholegrain products). Concurrently, there was a reduction in the consumption of
248 unhealthy foods, encompassing both animal and plant sources (red meat, refined cereals, sweetened
249 drinks and alcohol). A comparable trajectory was observed in the Netherlands, where a 20-year
250 (1993-2015) cohort analysis revealed positive shifts in dietary practices within isocaloric diets (35). In
251 contrast, findings from a Swedish study showed a deviation from Nordic dietary guidelines over time
252 (2000-2016) among participants in the Northern Sweden Diet Database (36). Furthermore, a similar
253 trend towards more plant-based diets has been observed throughout the WHO European region (15).
254 By extending the analysis to food groups, our research showed a decline in both red meat and
255 poultry consumption. These findings could be interpreted in light of the French household meat
256 purchase data for at-home consumption, revealing a declining trend of purchase volume of meat in
257 both 2021 and 2022 (37). However, when considering the apparent consumption of meat, an upturn
258 trend was observed over the same period, including out-of-home dining, as well as a significant
259 11.5% surge in French meat imports (37). Also, it has been shown that the decline in red meat
260 consumption noticed in France from the mid-2000s (- 12% in 10 years), has been, to some extent,
261 compensated by an increase in poultry consumption (38), while our results indicate a decrease in all
262 meat categories (except for processed meat). This could be partially attributed to certain specific
263 characteristics within our population, despite efforts made to adjust for the French census. However,

264 this might be seen in a different light, as a French survey (2010-2019) indicated that the substitution
265 of protein sources has remained heterogeneous (39). Thus, it is noteworthy that various approaches
266 to quantifying food consumption produce notably distinct results, compromising the precision and
267 relevance of comparisons. This disparity also applies to the composition of the considered food
268 groups. Therefore, the use of individual consumption data provides a more precise and
269 representative perspective of actual dietary habits.

270 Moreover, we observed an increase in the consumption of legumes, vegetables and fruits between
271 2014 and 2018, followed by a plateau in 2022. Indeed, the recent data from the Freshful
272 Consumption Monitor (40) revealed that 20 EU member states, including France in 2021, still
273 consume quantities of fruit and vegetable below the WHO's recommended daily consumption (at
274 least 400 g per day). Hypothesis related to the context such as inflation and Covid-19 pandemic may
275 explain such a slowdown in the transition to a diet more in line with sustainable recommendations.

276 Through the use of a gender-specific approach with energy-adjusted consumption data, our results
277 supported the existing literature (41–43) according to which gender emerges as a significant
278 determinant of dietary behaviors. We observed that men tended to consume a greater quantity of
279 animal products, energy-dense foods, and unhealthy items, while women exhibited a greater
280 inclination towards the consumption of plant-based and healthy foods. Indeed, when investigating
281 the obstacles to changing dietary behaviors, a notable gender-based contrast emerged in relation to
282 portion sizes and preferences (44). Previous works demonstrated that women are more inclined to
283 adopt diets rich in plant-based foods (45,46), while an American study indicated that men tended to
284 report less healthy lifestyles compared to women, marked by a reduced willingness to cut back on
285 meat consumption (44). In fact, gender is among the most influential predictor of meat consumption
286 levels (47,48), and this gender-related effect could be explained, to some extent, to the perception
287 associating meat consumption with masculinity (44). Moreover, the consumption trends of certain
288 unhealthy foods were advancing more rapidly over time among men than women. This is evident in
289 the increasing consumption of processed meat and butter, as well as the slower decline in

290 sweetened drinks and fruit juices among men. This pattern was also observed for legumes, where
291 the increase was more pronounced among women.

292 Furthermore, the observed changes in dietary patterns in our study were reflected in an
293 improvement in the quality of diets, as evidenced by the upward trajectories of the cDQI, aDQI, and
294 pDQI scores, with higher levels among women compared to men. The slight increase in the aDQI
295 score could be attributed to a more pronounced decline in unhealthy animal-based foods compared
296 to healthy ones. Regarding plant-based foods, the increased pDQI score might be explained by the
297 increase in healthy plant-based sources like legumes, nuts, and wholegrain products, contrasted with
298 a simultaneous decrease in unhealthy plant-based items, such as refined cereals, fruit juices, and
299 alcohol. A comparable result was achieved in the previously mentioned Dutch cohort, with an
300 improvement in the Dutch Healthy Diet Index 2015 score for both men (+11%) and women (+13%)
301 over two decades, mainly explained by an increased consumption of (shell)fish and nuts/seeds/nut
302 paste (35). Yet, an Australian study involving adults over 55 years old (2010-2014) showed that the
303 improvement in the quality of diets was evident only among men (49).

304 Also, the observed trends align with recommendations for promoting a sustainable dietary transition,
305 as the mentioned plant-based foods provide dual benefits for both health and the environment
306 (9,33,50–53). However, the Dutch study mentioned above noted no significant reduction in GHG
307 emissions despite a shift towards more sustainable diets. This underscores the ongoing necessity for
308 significant reductions in the consumption of animal-based foods, especially red meat (54), to achieve
309 diets that are both healthier and more environmentally friendly (35).

310 ***Dietary Transition and Socioeconomic Status***

311 Our results highlighted that individuals with higher education levels tended to consume less red meat
312 and more wholegrain products, while those with the lowest educational attainment demonstrated a
313 higher consumption of processed meat. Indeed, education level have an impact on the experience of
314 barriers to dietary change (55). Lower education levels are well-established correlates of poorer
315 dietary patterns, while higher education levels at baseline are predictive of a shift towards healthier

316 dietary patterns (48). Besides, a prior study on the same cohort NutriNet-Santé revealed that socially
317 favored individuals, with a higher level of education, exhibited healthier lifestyles and displayed a
318 significantly elevated Sustainable Diet Index (SDI) score (56). Another study found that individuals
319 with a higher level of education showed a preference for vegetarian diet (47). These patterns may be
320 partially attributed to the association between education levels, nutritional knowledge, and
321 environmental awareness. However, uncertainty persists about the effectiveness of nutritional
322 knowledge in public health nutrition due to the ongoing ambiguity surrounding the relationship
323 between the nature of knowledge and dietary behaviors (57). Yet, although of limited influence,
324 nutritional knowledge can play an important role in the adoption of healthier dietary behaviors (57).

325 Besides, our study revealed that income significantly influences dietary choices. Low-income
326 individuals consumed less red meat when compared to those with higher income. Yet, individuals
327 with higher income demonstrated a more substantial decline in meat consumption over time,
328 narrowing the consumption gap compared to those with lower income. These results align with a
329 study comparing meat consumption trends based on income in developed countries and the Kuznets
330 environmental curve (58). The comparison indicated an inverted U-shaped relationship, suggesting
331 that beyond a certain income threshold, increased awareness of environmental and health concerns
332 leads to reduced meat consumption (59).

333 Furthermore, our findings revealed that legumes were more consumed by individuals with the
334 lowest incomes and students. While being affordable, this food group plays a significant role in
335 sustainable dietary transition, with environmental and health co-benefits (30,60–62). However, it is
336 still under-consumed in high-income countries (63) and various barriers have been pointed out in the
337 literature. For instance, challenges related to sensory and preparation time and knowledge were
338 observed in Denmark and the UK, whereas participants from Germany, Spain, and Poland
339 encountered hurdles linked to digestive problems when incorporating pulses (64).

340 This prompts us to consider the significance of “perception” in shaping dietary preferences. Indeed,
341 adopting a sustainable diet is often perceived as costly, and studies revealed that affluent individuals

342 are more inclined to embrace sustainable dietary choices. The above-mentioned study on the
343 NutriNet-Santé cohort (56) revealed that within the subset of individuals with the highest SDI scores,
344 56.74% reported high incomes (>2700€/ C.U.). Conversely, affluent individuals tend to consume
345 more meat than their counterparts with lower incomes. Additionally, traditionally linked to lower-
346 income groups (65), sustainable foods like legumes are more consumed by individuals with limited
347 financial resources. In this context, two strategies for improving the perception of sustainable diets
348 emerge: optimizing the "price signal" of sustainable foods by incorporating externalities into costs,
349 and implementing communication campaigns and practical workshops to promote awareness of the
350 advantages of sustainable dietary choices.

351 ***Strengths and limitations***

352 As participants in the NutriNet-Santé cohort are voluntary, our sample is not representative of the
353 French population. Nonetheless, we have sought to mitigate this issue by weighting the data. Despite
354 a selection bias, our longitudinal study design offers unique insights into individual-level dietary
355 changes over time, a perspective not achievable through repeated cross-sectional surveys, thus
356 providing valuable contributions to understanding temporal trends in dietary patterns. Secondly, our
357 study did not account for potential changes in occupational position and income over time, as we
358 assumed that distinctions among the different classes remained consistent throughout the study
359 period. However, our study is among the few depicting recent individual changes in dietary behaviors
360 in a French cohort study. The substantial size of our sample enables us to explore a diverse range of
361 profiles, including individuals who have already initiated the transition to a sustainable diet. This
362 grants us the opportunity to analyze their profiles and gain insights from their trajectories. Moreover,
363 analyzing changes based on socioeconomic determinants provides relevant information to develop
364 targeted initiatives tailored to specific food groups and subgroups within the population.

365 ***Conclusion***

366 In conclusion, over the past 8 years (2014-2022), the dietary habits of French adults have witnessed
367 an increase in the consumption of healthy, plant-based foods and a decline in the consumption of
368 unhealthy foods of both animal and plant origin. The extent of these changes varied between
369 genders and resulted in an enhanced diet quality score (cDQI). Income, education level, and
370 occupational position appear to be determining factors of these observed changes. Our results offer
371 accurate information on current trends and associated factors, that could be used to formulate
372 targeted initiatives for specific food groups and subgroups within the population. This approach
373 seeks to direct strategic and personalized interventions, promoting a sustainable transition in dietary
374 habits.

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The authors' contributions are as follows:

EKG designed the research; HT performed statistical analysis; EKG supervised statistical analysis; HT drafted the manuscript; EKG supervised the writing. All authors contributed to the data interpretation, revised each draft for important intellectual content and approved the final manuscript.

EKG had primary responsibility for the final content, she is the guarantor. None of the authors reported a conflict of interest related to the study. The corresponding author (HT) attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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References

- 375 1. World Meteorological Organization [Internet]. 2024 [cited 2024 Aug 22]. European State of the
376 Climate 2023. Available from: [https://wmo.int/publication-series/european-state-of-climate-](https://wmo.int/publication-series/european-state-of-climate-2023)
377 2023
- 378 2. Campbell BM, Beare DJ, Bennett EM, Hall-Spencer JM, Ingram JSI, Jaramillo F, et al. Agriculture
379 production as a major driver of the Earth system exceeding planetary boundaries. *E&S*.
380 2017;22(4):art8.
- 381 3. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, Lambin EF, et al. A safe operating space
382 for humanity. *Nature*. 2009 Sep;461(7263):472–5.
- 383 4. Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, et al. Planetary
384 boundaries: Guiding human development on a changing planet. *Science*. 2015 Feb
385 13;347(6223):1259855.
- 386 5. Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip A. Food systems are
387 responsible for a third of global anthropogenic GHG emissions. *Nat Food*. 2021 Mar 8;2(3):198–
388 209.
- 389 6. WWF Germany & WWF Food Practice. ENHANCING NDCS FOR FOOD SYSTEMS
390 RECOMMENDATIONS FOR DECISION-MAKERS [Internet]. 2020. Available from:
391 [https://climatepromise.undp.org/sites/default/files/research_report_document/undp-ndcsp-](https://climatepromise.undp.org/sites/default/files/research_report_document/undp-ndcsp-wwf-unep-foodwaste-ndc-guide.pdf)
392 [wwf-unep-foodwaste-ndc-guide.pdf](https://climatepromise.undp.org/sites/default/files/research_report_document/undp-ndcsp-wwf-unep-foodwaste-ndc-guide.pdf)
- 393 7. COP28 Declaration on Food and Agriculture [Internet]. [cited 2024 Aug 22]. Available from:
394 <https://www.cop28.com/en/food-and-agriculture>
- 395 8. 21252030 Agenda for Sustainable Development web.pdf [Internet]. [cited 2024 Aug 23].
396 Available from:
397 [https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Su-](https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf)
398 [stainable%20Development%20web.pdf](https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf)
- 399 9. Springmann, Mason-D’Croz, Wiebe. Health and nutritional aspects of sustainable diet strategies
400 and their association with environmental impacts [Internet]. 2018 [cited 2022 Aug 24]. Available
401 from: [https://cloud.etude-nutrinet-](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-Environnement/Durabilit%C3%A9%20-%20Sant%C3%A9&fileid=276872)
402 [sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-Environnement/Durabilit%C3%A9%20-%20Sant%C3%A9&fileid=276872)
403 [Environnement/Durabilit%C3%A9%20-%20Sant%C3%A9&fileid=276872](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-Environnement/Durabilit%C3%A9%20-%20Sant%C3%A9&fileid=276872)
- 404 10. Poore, Nemecek. Reducing food’s environmental impacts through producers and consumers |
405 *Science* [Internet]. 2018 [cited 2022 Sep 11]. Available from:
406 <https://www.science.org/doi/10.1126/science.aaq0216>
- 407 11. Shukla PR, Skea J, Reisinger A, Slade R. Climate Change 2022 Mitigation of Climate Change.
- 408 12. Xu X, Sharma P, Shu S, Lin TS, Ciais P, Tubiello FN, et al. Global greenhouse gas emissions from
409 animal-based foods are twice those of plant-based foods. *Nat Food*. 2021 Sep 13;2(9):724–32.
- 410 13. Hallström E, Carlsson-Kanyama A, Börjesson P. Environmental impact of dietary change: a
411 systematic review. *Journal of Cleaner Production*. 2015 Mar;91:1–11.
- 412 14. Fouillet H, Dussiot A, Perraud E, Wang J, Huneau JF, Kesse-Guyot E, et al. Plant to animal protein
413 ratio in the diet: nutrient adequacy, long-term health and environmental pressure [Internet].

- 414 Nutrition; 2022 May [cited 2023 Feb 21]. Available from:
415 <http://medrxiv.org/lookup/doi/10.1101/2022.05.20.22275349>
- 416 15. WHO-EURO-2021-4007-43766-61591-eng.pdf [Internet]. [cited 2023 Oct 9]. Available from:
417 [https://iris.who.int/bitstream/handle/10665/349086/WHO-EURO-2021-4007-43766-61591-](https://iris.who.int/bitstream/handle/10665/349086/WHO-EURO-2021-4007-43766-61591-eng.pdf?sequence=1)
418 [eng.pdf?sequence=1](https://iris.who.int/bitstream/handle/10665/349086/WHO-EURO-2021-4007-43766-61591-eng.pdf?sequence=1)
- 419 16. Statista Daily Data [Internet]. 2024 [cited 2024 Sep 26]. Infographie: Quelle est la popularité des
420 régimes sans viande ? Available from: [https://fr.statista.com/infographie/28645/pourcentage-](https://fr.statista.com/infographie/28645/pourcentage-de-personnes-qui-suivent-un-regime-vegan-ou-vegetarien-par-pays)
421 [de-personnes-qui-suivent-un-regime-vegan-ou-vegetarien-par-pays](https://fr.statista.com/infographie/28645/pourcentage-de-personnes-qui-suivent-un-regime-vegan-ou-vegetarien-par-pays)
- 422 17. Évolution de la consommation des ménages selon l'âge de 2009 à 2019 – Transformations de
423 l'agriculture et des consommations alimentaires | Insee [Internet]. [cited 2024 Sep 26]. Available
424 from: <https://www.insee.fr/fr/statistiques/7728875?sommaire=7728903>
- 425 18. World Health Organization. A conceptual framework for action on the social determinants of
426 health. 2010;76.
- 427 19. Agurs-Collins T, Alvidrez J, ElShourbagy Ferreira S, Evans M, Gibbs K, Kowtha B, et al. Perspective:
428 Nutrition Health Disparities Framework: A Model to Advance Health Equity. *Adv Nutr.* 2024
429 *Apr*;15(4):100194.
- 430 20. Darmon N, Drewnowski A. Contribution of food prices and diet cost to socioeconomic disparities
431 in diet quality and health: a systematic review and analysis. *Nutr Rev.* 2015 Oct;73(10):643–60.
- 432 21. Bennett MK. Wheat in National Diets. *Wheat Studies* [Internet]. 1941 [cited 2024 Sep 25];18(02).
433 Available from: <https://econpapers.repec.org/article/agsfrisws/142802.htm>
- 434 22. Desbouys L, Méjean C, Henauw SD, Castetbon K. Socio-economic and cultural disparities in diet
435 among adolescents and young adults: a systematic review. *Public Health Nutrition.* 2020
436 *Apr*;23(5):843–60.
- 437 23. Hercberg S, Castetbon K, Czernichow S, Malon A, Mejean C, Kesse E, et al. The Nutrinet-Santé
438 Study: a web-based prospective study on the relationship between nutrition and health and
439 determinants of dietary patterns and nutritional status. *BMC Public Health.* 2010 May 11;10:242.
- 440 24. Vergnaud AC, Touvier M, Méjean C, Kesse-Guyot E, Pollet C, Malon A, et al. Agreement between
441 web-based and paper versions of a socio-demographic questionnaire in the NutriNet-Santé
442 study. *Int J Public Health.* 2011 Aug 1;56(4):407–17.
- 443 25. INSEE. Définition - Nombre d'unités de Consommation Du Ménage Fiscal | Insee.
444 <https://www.insee.fr/fr/metadonnees/definition/c1001>. 2009.
- 445 26. Baudry J, Méjean C, Allès B, Péneau S, Touvier M, Hercberg S, et al. Contribution of Organic Food
446 to the Diet in a Large Sample of French Adults (the NutriNet-Santé Cohort Study). *Nutrients.*
447 2015 Oct 21;7(10):8615–32.
- 448 27. NutriNet-Santé. Table de Composition Des Aliments ETUDE NUTRINET SANTE - Economica.
449 [https://www.economica.fr/livre-table-de-composition-des-aliments-etude-nutrinet-sante-](https://www.economica.fr/livre-table-de-composition-des-aliments-etude-nutrinet-sante-c2x32211075)
450 [c2x32211075](https://www.economica.fr/livre-table-de-composition-des-aliments-etude-nutrinet-sante-c2x32211075). 2013.
- 451 28. Keaver L, Ruan M, Chen F, Du M, Ding C, Wang J, et al. Plant- and animal-based diet quality and
452 mortality among US adults: a cohort study. *Br J Nutr.* 2021 Jun 28;125(12):1405–15.

- 453 29. La macro SAS CALMAR | Insee [Internet]. [cited 2023 Jun 8]. Available from:
454 <https://www.insee.fr/fr/information/2021902>
- 455 30. GBD 2019 Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and
456 territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet*.
457 2020 Oct 17;396(10258):1223–49.
- 458 31. Clark M, Hill J, Tilman D. The Diet, Health, and Environment Trilemma. *Annual Review of*
459 *Environment and Resources*. 2018;
- 460 32. Clark MA, Springmann M, Hill J, Tilman D. Multiple health and environmental impacts of foods.
461 *Proc Natl Acad Sci USA*. 2019 Nov 12;116(46):23357–62.
- 462 33. Auestad N, Fulgoni VL. What Current Literature Tells Us about Sustainable Diets: Emerging
463 Research Linking Dietary Patterns, Environmental Sustainability, and Economics. *Advances in*
464 *Nutrition*. 2015 Jan;6(1):19–36.
- 465 34. Springmann M, Wiebe K, Mason-D’Croz D, Sulser TB, Rayner M, Scarborough P. Health and
466 nutritional aspects of sustainable diet strategies and their association with environmental
467 impacts: a global modelling analysis with country-level detail. *The Lancet Planetary Health*. 2018
468 Oct 1;2(10):e451–61.
- 469 35. Biesbroek S, Verschuren WM, Boer JM, Van Der Schouw YT, Sluijs I, Temme EH. Are our diets
470 getting healthier and more sustainable? Insights from the European Prospective Investigation
471 into Cancer and Nutrition – Netherlands (EPIC-NL) cohort. *Public Health Nutr*. 2019
472 Nov;22(16):2931–40.
- 473 36. Huseinovic E, Hörnell A, Johansson I, Esberg A, Lindahl B, Winkvist A. Changes in food intake
474 patterns during 2000-2007 and 2008-2016 in the population-based Northern Sweden Diet
475 Database. *Nutr J*. 2019 Jul 12;18(1):36.
- 476 37. SYN-VIA-Conso viande Fce2022.pdf [Internet]. [cited 2023 Oct 9]. Available from:
477 [https://www.franceagrimer.fr/content/download/71709/document/SYN-VIA-](https://www.franceagrimer.fr/content/download/71709/document/SYN-VIA-Conso%20viande%20Fce2022.pdf)
478 [Conso%20viande%20Fce2022.pdf](https://www.franceagrimer.fr/content/download/71709/document/SYN-VIA-Conso%20viande%20Fce2022.pdf)
- 479 38. Testut-Neves M. LES ETUDES de FranceAgriMer 2018 / ÉLEVAGE/Viande bovine/Tome1/.
- 480 39. Perraud S. Evolutions de la consommation de protéines par sources alimentaires entre 2010 et
481 2019 selon les profils de consommateurs. 2020 Dec 16 [cited 2023 Oct 4]; Available from:
482 <https://zenodo.org/record/4327397>
- 483 40. Consumption Monitor | Freshfel [Internet]. [cited 2023 Oct 17]. Available from:
484 <https://freshfel.org/what-we-do/consumption-monitor/>
- 485 41. Vari R, Scazzocchio B, Papa SD. Dietary habits and gender differences.
- 486 42. Li KK, Concepcion RY, Lee H, Cardinal BJ, Ebbeck V, Woekel E, et al. An Examination of Sex
487 Differences in Relation to the Eating Habits and Nutrient Intakes of University Students. *Journal*
488 *of Nutrition Education and Behavior*. 2012 May;44(3):246–50.
- 489 43. Wardle J, Haase AM, Steptoe A, Nillapun M, Jonwutiwes K, Bellisle F. Gender differences in food
490 choice: the contribution of health beliefs and dieting. *Ann Behav Med*. 2004 Apr;27(2):107–16.

- 491 44. Nakagawa S, Hart C. Where's the Beef? How Masculinity Exacerbates Gender Disparities in
492 Health Behaviors. *Socius*. 2019 Jan 1;5:2378023119831801.
- 493 45. Satija A, Hu FB. Plant-based diets and cardiovascular health. *Trends in Cardiovascular Medicine*.
494 2018 Oct;28(7):437–41.
- 495 46. Derbyshire EJ. Flexitarian Diets and Health: A Review of the Evidence-Based Literature. *Front*
496 *Nutr*. 2017 Jan 6;3:55.
- 497 47. Stoll-Kleemann S, Schmidt UJ. Reducing meat consumption in developed and transition countries
498 to counter climate change and biodiversity loss: a review of influence factors. *Reg Environ*
499 *Change*. 2017 Jun 1;17(5):1261–77.
- 500 48. Tobler C, Visschers VHM, Siegrist M. Eating green. Consumers' willingness to adopt ecological
501 food consumption behaviors. *Appetite*. 2011 Dec;57(3):674–82.
- 502 49. Thorpe MG, Milte CM, Crawford D, McNaughton SA. Education and lifestyle predict change in
503 dietary patterns and diet quality of adults 55 years and over. *Nutr J*. 2019 Nov 7;18(1):67.
- 504 50. Clark, Hill, Tilman. The Diet, Health, and Environment Trilemma [Internet]. 2018 [cited 2022 Aug
505 24]. Available from: [https://cloud.etude-nutrinet-](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/R%C3%A9gimes/R%C3%A9gime%20Mediterranee/Durabilit%C3%A9%20au%20global&fileid=1271145)
506 [sante.fr/index.php/apps/files/?dir=/2_BIBLIO/R%C3%A9gimes/R%C3%A9gime%20Mediterranee](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/R%C3%A9gimes/R%C3%A9gime%20Mediterranee/Durabilit%C3%A9%20au%20global&fileid=1271145)
507 [n/Durabilit%C3%A9%20au%20global&fileid=1271145](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/R%C3%A9gimes/R%C3%A9gime%20Mediterranee/Durabilit%C3%A9%20au%20global&fileid=1271145)
- 508 51. Weindl, Ost, Wiedmer. Sustainable food protein supply reconciling human and ecosystem
509 health: A Leibniz Position [Internet]. 2020 [cited 2022 Sep 11]. Available from:
510 [https://cloud.etude-nutrinet-](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-Environnement/Syst%C3%A8mes_durables_transition&fileid=289928)
511 [sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-Environnement/Syst%C3%A8mes_durables_transition&fileid=289928)
512 [Environnement/Syst%C3%A8mes_durables_transition&fileid=289928](https://cloud.etude-nutrinet-sante.fr/index.php/apps/files/?dir=/2_BIBLIO/%2BDurabilit%C3%A9-Environnement/Syst%C3%A8mes_durables_transition&fileid=289928)
- 513 52. Mariotti F. Protéines animales et végétales : quels effets sur la santé cardio-métabolique ?
514 *Médecine des Maladies Métaboliques*. 2019 May;13(3):245–51.
- 515 53. Toujgani H, Brunin J, Perraud E, Allès B, Touvier M, Lairon D, et al. The nature of protein intake as
516 a discriminating factor of diet sustainability: a multi-criteria approach. *Sci Rep*. 2023 Oct
517 19;13(1):17850.
- 518 54. Hjorth T, Huseinovic E, Hallström E, Strid A, Johansson I, Lindahl B, et al. Changes in dietary
519 carbon footprint over ten years relative to individual characteristics and food intake in the
520 Västerbotten Intervention Programme. *Sci Rep*. 2020 Jan 8;10(1):20.
- 521 55. Naska A, Fouskakis D, Oikonomou E, Almeida MDV, Berg MA, Gedrich K, et al. Dietary patterns
522 and their socio-demographic determinants in 10 European countries: data from the DAFNE
523 databank. *Eur J Clin Nutr*. 2006 Feb;60(2):181–90.
- 524 56. Seconda L, Baudry J, Pointereau P, Lacour C, Langevin B, Hercberg S, et al. Development and
525 validation of an individual sustainable diet index in the NutriNet-Santé study cohort. *British*
526 *Journal of Nutrition*. 2019 May;121(10):1166–77.
- 527 57. Worsley A. Nutrition knowledge and food consumption: can nutrition knowledge change food
528 behaviour? *Asia Pacific Journal of Clinical Nutrition*. 2002;11(s3):S579–85.

- 529 58. Dinda S. Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics*. 2004
530 Aug;49(4):431–55.
- 531 59. Vranken L, Avermaete T, Petalios D, Mathijs E. Curbing global meat consumption: Emerging
532 evidence of a second nutrition transition. *Environmental Science & Policy*. 2014 May 1;39:95–
533 106.
- 534 60. Voisin AS, Guéguen J, Huyghe C, Jeuffroy MH, Magrini MB, Meynard JM, et al. Legumes for feed,
535 food, biomaterials and bioenergy in Europe: a review. *Agron Sustain Dev*. 2014 Apr 1;34(2):361–
536 80.
- 537 61. Semba RD, Ramsing R, Rahman N, Kraemer K, Bloem MW. Legumes as a sustainable source of
538 protein in human diets. *Global Food Security*. 2021 Mar 1;28:100520.
- 539 62. Havemeier S, Erickson J, Slavin J. Dietary guidance for pulses: the challenge and opportunity to
540 be part of both the vegetable and protein food groups. *Annals of the New York Academy of
541 Sciences*. 2017;1392(1):58–66.
- 542 63. Huebbe P, Rimbach G. Historical Reflection of Food Processing and the Role of Legumes as Part
543 of a Healthy Balanced Diet. *Foods*. 2020 Aug;9(8):1056.
- 544 64. Henn K, Goddyn H, Olsen SB, Bredie WLP. Identifying behavioral and attitudinal barriers and
545 drivers to promote consumption of pulses: A quantitative survey across five European countries.
546 *Food Quality and Preference*. 2022 Jun 1;98:104455.
- 547 65. Albala K. *Beans: A History*. Bloomsbury Publishing; 2017. 270 p.

Tables

Table 1: Participant characteristics, n = 17,187, NutriNet-Santé Study^{1,2}

| | Whole Sample | Women | Men | P |
|--------------------------------------------|---------------|---------------------|--------------------|----------|
| Unweighted n | n = 17,187 | n = 12,479 (72.61%) | n = 4,708 (27.39%) | |
| Weighted n | n = 17,187 | n = 8,999 (52.36%) | n = 8,188 (47.64%) | |
| Age | 48.38 (15.97) | 48.81 (13.68) | 47.90 (20.83) | < 0.0001 |
| Education level | | | | < 0.0001 |
| Primary | 59.92 | 58.59 | 61.39 | |
| Secondary | 15.19 | 15.88 | 14.43 | |
| Post-secondary | 24.89 | 25.53 | 24.19 | |
| Occupational position | | | | < 0.0001 |
| Self-employed/farmer | 4.45 | 2.42 | 6.67 | |
| Managerial staff/intellectual profession | 9.10 | 6.74 | 11.69 | |
| Unemployed | 8.85 | 12.63 | 4.69 | |
| Employee. manual worker | 31.19 | 30.53 | 31.90 | |
| Students | 4.49 | 4.60 | 4.40 | |
| Intermediate professions | 14.50 | 14.47 | 14.53 | |
| Retired | 27.42 | 28.61 | 26.12 | |
| Monthly income per household unit | | | | < 0.0001 |
| NA | 6.58 | 8.49 | 4.48 | |
| < 1200€/C.U. | 24.42 | 27.64 | 20.89 | |
| 1200 - 1800€/ C.U. | 30.91 | 28.53 | 33.52 | |
| 1800 - 2700€/ C.U. | 23.39 | 22.11 | 24.80 | |
| >2700€/ C.U. | 14.70 | 13.23 | 16.31 | |
| Place of residence | | | | < 0.0001 |
| Rural community | 23.99 | 25.62 | 22.19 | |
| Urban unit (<20,000 inhabitants) | 18.63 | 16.50 | 20.95 | |
| Urban unit (20,000 to 200,000 inhabitants) | 16.80 | 18.30 | 15.17 | |
| Urban unit (>200,000 inhabitants) | 40.58 | 39.57 | 41.70 | |
| Smoking habits | | | | < 0.0001 |
| Never smoker | 50.16 | 55.60 | 44.17 | |
| Former smoker | 39.02 | 33.71 | 44.85 | |
| Current smoker | 10.83 | 10.69 | 10.98 | |
| Physical activity | | | | < 0.0001 |
| Low | 20.30 | 20.26 | 20.35 | |
| Moderate | 31.16 | 31.68 | 30.59 | |
| High | 32.89 | 33.53 | 32.18 | |
| Missing data | 15.65 | 14.53 | 16.88 | |
| BMI | | | | < 0.0001 |
| Underweight (<18.5 kg/m ²) | 3.70 | 5.94 | 1.24 | |
| Healthy (18.5 - 24.9 kg/m ²) | 55.75 | 58.55 | 52.67 | |
| Overweight (25 - 29.9 kg/m ²) | 26.90 | 21.30 | 33.06 | |
| Obese (≥ 30 kg/m ²) | 13.64 | 14.21 | 13.03 | |
| BMI | 24.94 (4.99) | 24.54 (4.44) | 25.38 (6.17) | < 0.0001 |

Abbreviations: BMI, body mass index; C.U., consumption unit.

¹Values are mean (SD) or % as appropriate, all data are weighted.

²P values calculated using ANOVA or Chi² test.

Figures:

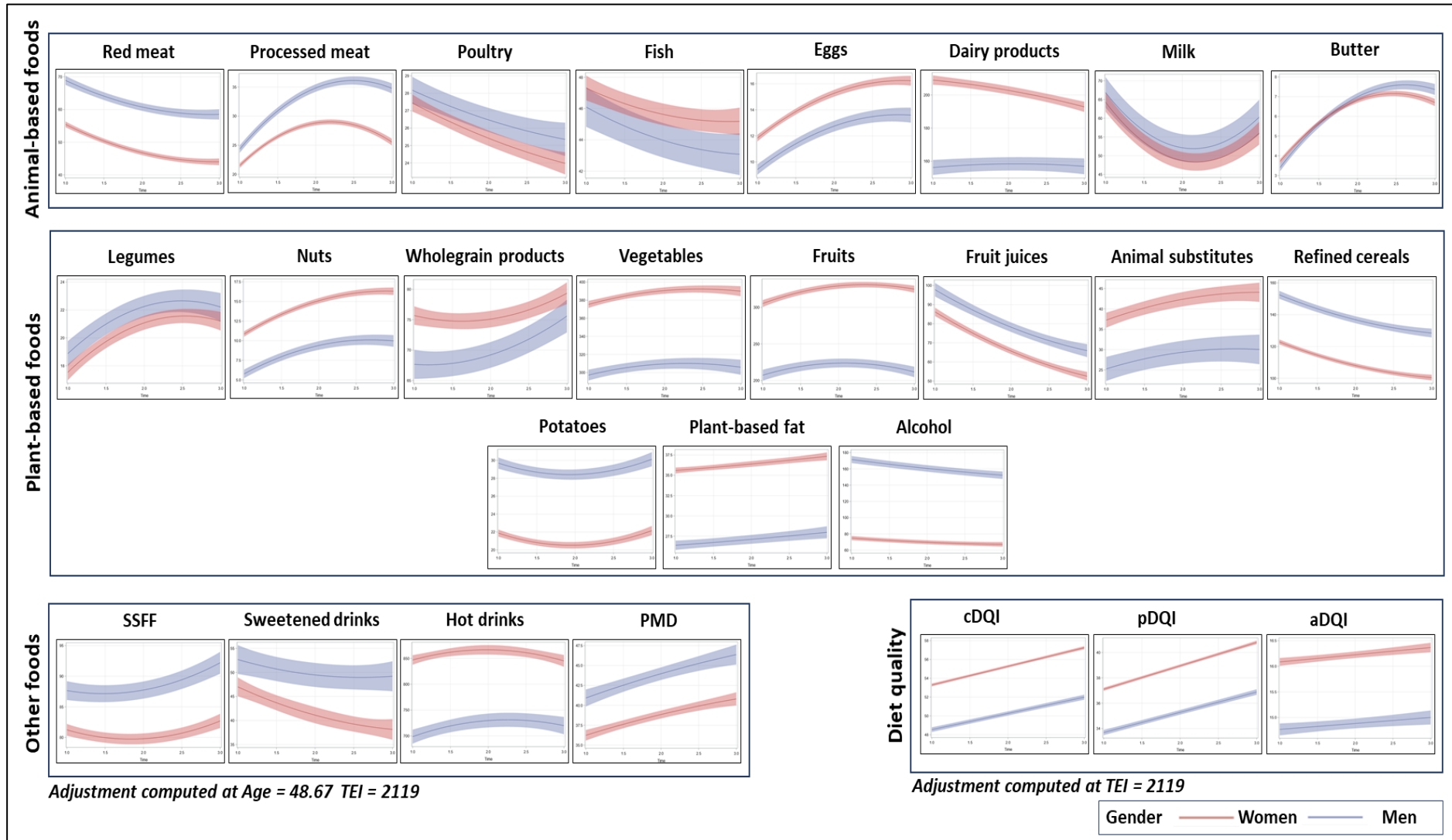


Figure 1: Evolution trajectories for food groups' consumption and diet quality (2014 to 2022), n = 17,187, NutriNet-Santé Study^{1,2,3}

Food groups are formed as follows: Red meat include beef, pork, offal, lamb; Dairy products include yogurts, fresh cheese and cheese; Animal substitutes include tofu, soy-based meat substitute and vegetable patties, soy-based yogurt, soy-based milk; Vegetables include all vegetables and soups; Fruit include fresh fruit, fruit in syrup and compote, dried fruit and seeds; Fish include fatty and lean fish, mollusks, and crustaceans; Potatoes include other tubers; Refined cereals include breakfast cereal low in sugar, bread, semolina, rice and pasta; SSFF (sweetened and salty fatty foods) include croissants, pastries, chocolate, biscuits, milky dessert, ice cream, honey and marmalade, cakes, chips, salted oilseeds, salted biscuits; PMD (prepared and mixed dishes) include sandwich, prepared foods such as pizza, hamburger, ravioli, panini, salted pancake, etc.; Plant-based fat include plant-based oils and ready-to-use salad dressing, mayonnaise or cream-based sauces, sour cream and all fat-based sauces; Hot drinks include tea, infusions, milk consumed with tea/coffee; Sweetened drinks include fruit nectar, syrup, soda (with or without sugar), plant-based beverages.

¹Abbreviations: TEI, Total energy intake over time; SSFF, Sweetened / Salty and Fatty Foods; PMD, Prepared and Mixed Dishes; cDQI, Comprehensive Diet Quality Index; pDQI, plant-based Diet Quality Index; aDQI, animal-based Diet Quality Index.

²For the 23 food groups, adjustment have been computed at Age=48.67 years and TEI=2119 kcal/d; For the Diet Quality Indexes, adjustment have been computed at TEI=2119 kcal/d.

³The x-axis represents time (1=2014; 2=2018; 3=2022), while the y-axis represents consumption in grams per day.

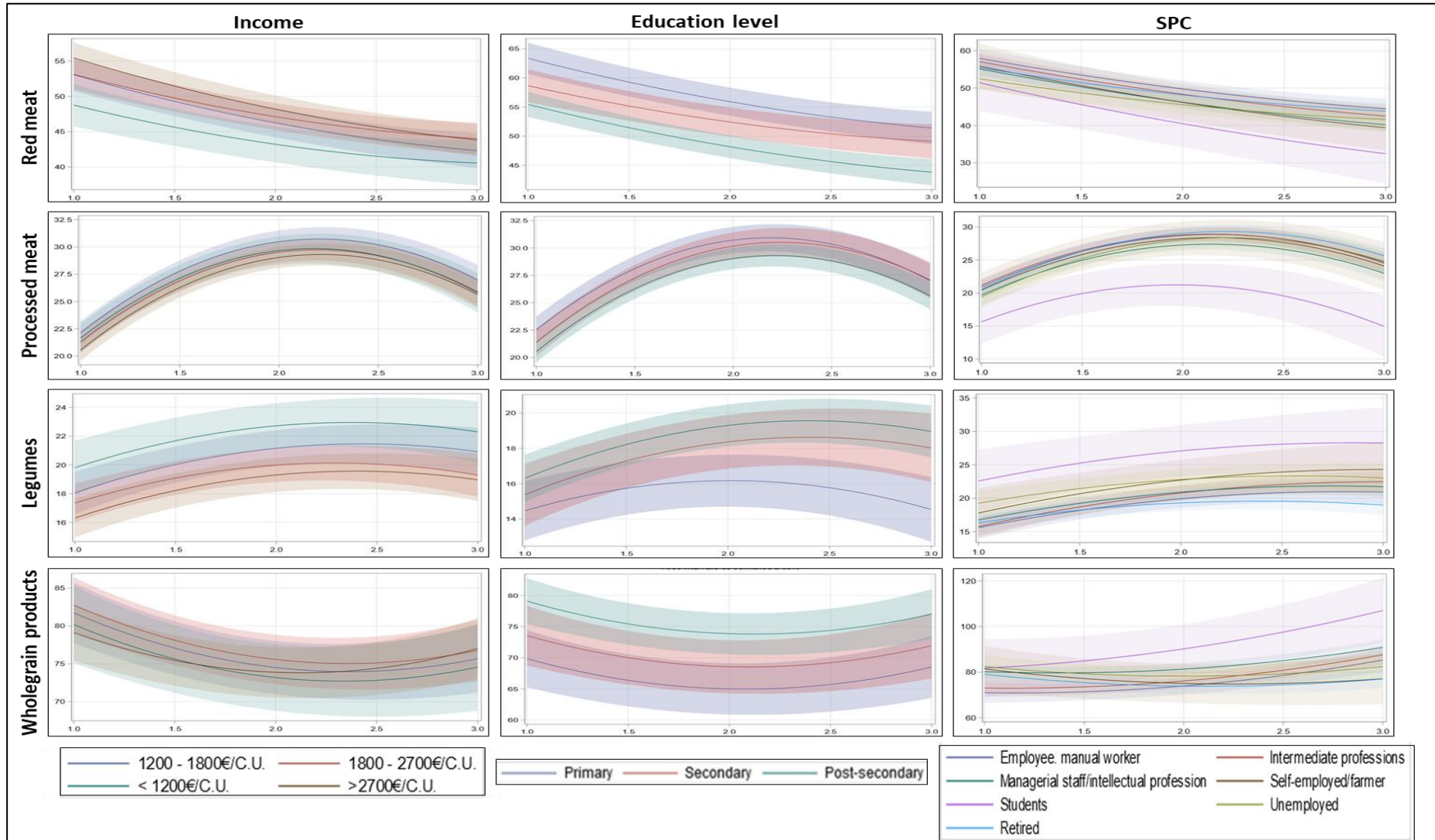


Figure 2: Socioeconomic determinants of the consumption evolution for the 4 food groups strongly associated with mortality risk (red meat, processed meat, legumes, and whole-grain products) between 2014 and 2022, n = 17 187, NutriNet-Santé Study^{1,2}

¹ Adjustment computed at Age = 48.8; TEI = 2133; Gender = Women; Occupational status = Retired; Income >2700 €/CU; Education = Post-secondary

² The x-axis represents time (1=2014; 2=2018; 3=2022), while the y-axis represents consumption in grams per day.