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ABSTRACT

Many studies have demonstrated the environmental and health weaknesses of the food systems and the need for transformation is now recognised. Although some consumer segments seem to be more aware of sustainability issues, sustainable motives do not systematically translate into purchasing behaviour. The aims of this study were to identify a typology of dietary changes and to analyse whether these actual dietary changes towards more sustainable consumption during the years 2014–2018, (considering nutritional quality, plant-based foods and organic consumption) were related to a set of consumer food purchase motives measured in 2013.

In the French NutriNet-Santé cohort, 13,292 individuals completed a food frequency questionnaire in 2014 and 2018 and a validated food purchase motives questionnaire in 2013, with a particular focus on sustainability. A typology was built to identify clusters using a Reduce Rank Regression (RRR) statistical model, with differences in food consumption as predictor variables and a set of dietary scores (reflecting nutritional quality, plant-based food and organic consumption) as response variables. Associations between dietary changes and food purchase motives were evaluated using ANCOVA.

Participants with the most sustainable diet in 2014 and that has continued to improve over time (increased healthy plant-based foods and organic consumption) showed higher sustainable food-purchase motives. These were more often women, young and graduates. Participants with the lowest sustainable motives had at the same time a rather unsustainable diet and changed to a greatly improved diet in 2018. Participants with strong motives related to price, innovation and convenience showed a decrease in diet quality over time (increase in unhealthy plant- and animal-based food, alcoholic drinks, decrease in organic consumption). This cluster had the highest proportion of men, less educated and older than 65.

Our results indicate that a part of the population was interested in sustainable food purchase and improved the sustainability of their diet over a short period of time. Some participants, with specific socio-demographic characteristics, were unaware of their diet's sustainability. Therefore, targeting awareness of food sustainability to a certain part of the population is essential.

1. Introduction

Current westernised diets are rich in meat, processed food, poor in nutrients and include a high proportion of fat, sugar and salt, causing deleterious impacts on health (WHO Team Nutrition, 2018; World Cancer Research Fund International, 2008; WHO/FAO, 2003; Schoeller, 2008). This type of diet combined with globalisation, has led to intensification of food production, and greatly contributes to greenhouse gas emissions (GHG), a dramatic loss of biodiversity, a depletion of fresh

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Abbreviations

aDQI	Animal-based Diet Quality Index
ANSES	Agence Nationale de Sécurité Sanitaire de l'Alimentation, de l'Environnement et du Travail
BMI	Body Mass Index
cDQI	Comprehensive Diet Quality Index
CEEI	INSERM Ethical Evaluation Committee
CU	consumption unit
CNIL,	Comission Nationale de l'Informatique et des Libertés
FAO	Food and Agriculture Organization
FFQ	Food Frequency Questionnaire;
GHGe	Greenhouse gas emissions
hPDI	Healthful Plant-based Diet Index
INSERM	Institut National de la Santé et de la Recherche Médicale
IPAQ	International Physical Activity Questionnaires
Org-FFQ	Organic Food Frequency Questionnaire;
PANDiet,	Diet Quality Index Based on the Probability of Adequate Nutrient Intake
PDI	Plant-based Diet Index
pDQI	Plant-based Diet Quality Index
PNNS	Programme National Nutrition Santé
PNNS-GS2	Programme National Nutrition Santé-Guideline Score 2
PNNS-GS	Programme National Nutrition Santé-Guideline Score; RRR, Reduce Rank Regression
SD	standard deviation
uPDI	Unhealthful Plant-based Diet Index

water and energy use (Aleksandrowicz et al., 2016; Willett et al., 2019). According to scientific experts, our current food system is not compatible with climate change mitigation objectives (Mbow et al., 2019; Tilman and Clark, 2014; WHO Team Nutrition, 2018).

In this urgent context, the Food and Agriculture Organization (FAO) has defined sustainable food as food that contributes to protecting and respecting biodiversity and ecosystems, is culturally acceptable, economically equitable and accessible, affordable, nutritionally safe and healthy, and optimizes natural and human resources (Willett et al., 2019). These new diets to be followed towards a more sustainable transition are well documented and are composed of more plant-based food and less animal-based food, richer in fibres, more legumes, more organically produced foods etc. (Aleksandrowicz et al., 2016; Frehner et al., 2021; Garnett, 2014; Gomiero, 2018; Poore and Nemecek, 2018; Reganold and Wachter, 2016; Wellesley et al., 2015). Due to its lower crop yields per area (Seufert and Ramankutty, 2017), concerns have been raised about the ability of organic food system to feed a growing population (Meemken and Qaim, 2018). However, organic food systems encompass different sustainability features, as underlined by (Gomiero, 2018; Strassner et al., 2015). It is also well documented that organic farming is more beneficial to biodiversity, soil quality, including the non-use of pesticides and ecosystem services than intensive farming and that it provides social and ecosystem benefits (Reganold and Wachter, 2016; Rempelos et al., 2021). Besides, many studies have documented the profiles of organic food consumers (Baudry et al., 2017; Hoffmann and Wivstad, 2015; Hughner et al., 2007; Pino et al., 2012; Saraiva, 2017). Various motives can influence organic food purchase such as health, environment preservation, taste, or ethics which may, in turn, led to sustainable food choices. Awareness of the impacts of food production in recent years has been growing among some consumers' groups, who seem to have started a transition towards sustainability (Biesbroek et al., 2019; Hjorth et al., 2020). However, many consumers do not consider the consumption of organic products or the reduction of meat consumption as possible levers to reduce environmental impacts (de Boer and Aiking, 2022; Hansmann et al., 2020). Among the levers for improving sustainable food consumption, we can note that consumers have a considerable influence on the food market, especially through their purchases acting on the demand (Grunert and Grunert, 2011; The High Level Panel of Experts, 2014). Their individual behaviours would be one of the levers for reaching sustainability (Grunert and Grunert, 2011; The High Level Panel of Experts, 2014). According to a survey conducted in 2020, 58% of French people believe that in order to cope with climate change, they will have to adapt their lifestyle (ADEME, 2021). However, various factors (health problems, social environment, nutritional education) and barriers (convenience, selfish and altruistic motives, price) can influence food behaviour towards sustainability leading to inconsistent findings (Biasini et al., 2021). For example, Culliford et al. and Grunert et al. have shown that consumers' sustainable food purchase motives do not lead to sustainable food purchasing behaviour (Culliford and Bradbury, 2020; Grunert and Grunert, 2011) while conversely, Allès et al. and Baudry et al. have shown that motives may induce a sustainable diet (Allès et al., 2017; Baudry et al., 2017). Different factors can influence food purchases, such as external factors (availability, price, marketing), but also socio-cultural factors (culture, habits, socioeconomic status) and individual factors (taste, values, knowledge) (Fresán et al., 2020; Kollmuss and Agyeman, 2002; Stoll-Kleemann and Schmidt, 2017; Thøgersen, 2005).

Nevertheless, some research revealed more sustainable eating behaviours among consumers reporting sustainability-related food purchase motives. For example, the most interested in animal welfare are vegetarians. This motivation may have generated a dietary change by removing meat (de Boer et al., 2017). Besides, those who are less sensitive to sustainable motives, who would be men and younger, would be the least likely to change their diet towards more sustainable diets (Clonan et al., 2015; Rejman et al., 2019).

The first objective of this study was to develop, in a large sample of French adults, a typology of dietary changes over a 4-year period (2014–2018) using the reduced rank regression (RRR) method with dietary change indicators as response variables. We then conducted a partitioning method to derive clusters based on the RRR-extracted factors. The second objective was, using food purchasing motive data, including sustainability-related motives, measured in 2013, to characterise motives associated with clusters of dietary change, to explore whether sustainable motives did translate into actual dietary changes towards more sustainability and, in particular, towards more plant-based diets.

2. Material and methods

The NutriNet-Santé study is a French cohort designed to study the relationship between nutrition and health and their determinants. The study, which started in 2009 on a dedicated web platform, includes adult (over 18 years old) volunteer participants. To be included in the study and then once or twice a year, participants are asked to complete five questionnaires on food consumption, health status, anthropometry, sociodemographic and lifestyles. Additional questionnaires are proposed to document specific topics such as dietary supplements, breathing health, skin etc. This study is validated by both the National Committee for Information Technology and Freedom (CNIL) under numbers 908450 and 909216 and by the INSERM Ethical Evaluation Committee (CEEI) under number 0000388FWA00005831. It complies with the principles of the Declaration of Helsinki and is registered under ClinicalTrials.gov (NCT03335644). Detailed information of the NutriNet-Santé cohort were published elsewhere (Hercberg et al., 2010).

Several self-administered individual characteristic data were included in this study, such as gender, age (classified into 4 categories:

18–35, 35–50, 50–65 and over 65y), educational level (less than high school diploma, high school diploma, postgraduate), occupational status (unemployed, never employed, self-employed/farmer, employee/manual worker, intermediate professions, managerial staff/intellectual profession, and retired) and monthly household incomes (less than EUR 1,200, between EUR 1200 and EUR 1,800, between EUR 1800 and EUR 2,700, between EUR 1800 and EUR 2,700, between EUR 1800 and EUR 2700 and more than EUR 2700). Income was calculated according to the number and age of each person in the household (INSEE, 2016).

Other data related to lifestyle characteristics were used such as physical activity (low, moderate, high, missing data) according to the International Physical Activity Questionnaires (IPAQ) (Hallal and Victora, 2004) and smoking status (non-smoker, former smoker, smoker).

Finally, anthropometric data such as the body mass index (BMI) (less or equal 25 kg/m2, between 25 and 30 kg/m2 and more than 30 kg/m2) was calculated and validated according to the weight/height squared formula (Lassale et al., 2013).

Dietary intakes were derived from a food frequency questionnaire (FFQ) extensively described elsewhere (Baudry et al., 2015). This questionnaire covered consumption of 264 food and beverage items over the preceding year and was based on a previously validated questionnaire (Kesse-Guyot et al., 2010). Organic and non-organic food consumptions were estimated for each participant in grams per day using the same food frequency questionnaire (Org-FFQ) in 2014 and 2018. For each item, participants were asked to fill in according to the following choices: daily, weekly, monthly, or yearly. Next, the quantities were estimated with the use of tips such as pictures with different portion sizes (seven choices are possible), the use of portion units (a yoghurt, a slice of ham, an egg, etc.). or standard quantities (a teaspoon, a glass, etc.) (Baudry et al., 2015).

Several complementary scores reflecting the different components of the diets were used to assess nutritional quality, plant-based dietary patterns and organic consumption.

For each item of the Org-FFQ questionnaire, the frequency of organic consumption was asked using a Likert scale: always, often, about ½ time, rarely or never. Then, to obtain a consumption in g/d, this scale was translated into 100, 75, 50, 25 and 0% of the total consumption. The organic consumption was therefore the sum of these consumptions. Sensitivity analyses were performed in a previous study (Monte Carlo simulations) (Baudry et al., 2015).

We considered two nutritional quality scores. The first one, the "Programme National Nutrition Santé Guidelines Score 2" (PNNS-GS2 score) measures the adherence to French food-based dietary recommendations, and ranges from -∞ to 14.25 **(Supplemental Material 1)**. More information on this score can be found elsewhere (Chaltiel et al., 2019; Kesse-Guyot et al., 2021).

The second, the Diet Quality Index based on the Probability of Adequate Nutrient Intake (PANDiet score) assesses the adequacy of 28 nutrients to the nutritional references of the Agency for Food, Environmental, and Occupational Health and Safety (ANSES). The PANDiet score ranges from 0 to 100, and is the average of a moderation and an adequation sub-scores (**Supplemental Material 2**). More details are provided elsewhere (de Gavelle et al., 2018; Verger et al., 2012).

In addition, other existing scores were used to evaluate the proportion of plant-based foods in the diet. The plant-based diet index (PDI) score is composed of ascending points (from 1 to 5, 5 for highest plant consumption) allocated to plant food groups and descending points allocated to animal food groups. Points are based on unadjusted quintiles values of the 2014 food intakes of participants that completed the Org-FFQ in 2014. This results in the healthful plant-based diet index (hPDI) score and the unhealthful plant-based diet index (uPDI) score, which differentiated healthy and unhealthy plant-based products (Supplemental Table 1). The three scores range from 12 to 60. More information is available elsewhere (Satija et al., 2016).

The comprehensive diet quality index (cDQI), ranging from 0 to 85, is the sum of the plant-based diet quality index (pDQI) and the animal-based diet quality index (aDQI). The latter are estimated either by thresholds based on literature evidence or by crude consumption quintiles of participants who completed the Org-FFQ in 2014 and 2018. The aim of this score is to discriminate between the consumption of healthy and unhealthy plant and animal products. (Supplemental Table 2). More details were available elsewhere (Keaver et al., 2020).

The questionnaire, including a set of 63 questions, was administered in 2013 to assess food purchase motives, with a particular focus on sustainability. Initially, the questions were about general food purchases and then the questions were on specific foods: meat, fish, dairy products and, fruits and vegetables. The different themes were introduced by "when I buy a food, I take into account … " for the generic questions and on the 4 food groups. The questions were on a 5-point Likert scale to measure the level of agreement: "strongly disagree" to "strongly agree". In addition, the personal consumption of the 4 main food groups (meat/fish/fruit and vegetables/dairy products) was asked: "often/sometimes/never". The participants who declared to consume the food filled in their reasons of consumption: taste, impact on the environment, effect on their health, origin, price, simplicity of preparation. All the participants also completed their reasons of non-consumption (environmental, health, ideology/belief). The questionnaire was developed and validated within this cohort (using factorial analysis). Nine main dimensions (first-order dimension) were extracted from the validation procedure: absence of contaminants, environmental limitations or avoidance for environmental reasons, ethics and the environment, taste, innovation, local and traditional production, price, health, and convenience. A second order dimension, called "healthy and environmentally friendly consumption", includes the four first order dimensions "ethics and environment", "traditional and local production", "health" and "absence of contaminants" and reflects different aspects of sustainability. The questionnaire's feasibility, reliability (repeatability and internal consistency), and internal validity were all satisfactory (Sautron et al., 2015). More information on the development of the questionnaire and analysis are available elsewhere (Baudry et al., 2017; Steptoe et al., 1995) and in Supplemental Table 3.

Data on social desirability bias were collected in September 2014 using a validated questionnaire including 36 questions about personality (subjective well-being, self-esteem, affectivity etc.) with the aim to measuring self-dupery and heterodupery (lack of self-knowledge vs. control of self-image). For each item, a 7-level scale was used from "completely false" to "completely true" (range of 2–10) (Jocelyne et al., 2000).

Only participants who completed the Org-FFQ in 2014, and in 2018 and the Food Purchase Motive Questionnaire were selected. After exclusion of participants due to missing covariates, under or over reporting or living outside metropolitan France (N = 2863), the Org-FFQ of 2014 and 2018 were completed by 34,442 and 25,721 participants respectively and the 18,108 respondents who completed both were selected. Next, we selected the 13,292 participants who had also completed questionnaire about food purchase motives (Supplemental Fig. 1).

The 264 foods and beverages were grouped into twenty-two food subgroups: whole-grain products; vegetables; fruit; nuts, seeds, legumes; vegetable oils; coffee, tea; fruit juices; refined grains; potatoes; sugar-sweetened beverages; sweets and desserts; fish, seafood; dairy products; poultry; processed meat; meat; eggs; other fat; other fatty, salty, and sweet products; dairy and meat substitutes; alcoholic beverages and other non-alcoholic beverages. Four groups were created according to the classification of the cDQI score, i.e. unhealthy and healthy animal and plant products (Supplemental Table 4).

A two-step procedure was carried out to identify clusters as follows. The first step was to use the RRR method, a method using a linear function of predictors and the second step consisted of using a clustering method (Hoffmann, 2004). The aim of the RRR is to maximise the variability of the response variables (multidimensional consideration of changes in nutritional quality, plant-based dietary patterns and organic consumption) (Supplemental Fig. 2). More precisely, the 9 response variables were the differences between 2018 and 2014 for the PDI score, hPDI score, uPDI score, aDQI score, pDQI score, organic consumption, plant to total protein ratio, PNNS-GS2 score and PANDiet score. The cDQI score was not included in the response variables as it was highly correlated with the pDQI score (r = 0.83). Predictors variables were differences between follow-up intake and baseline intake at the individual level (44 predictors: 22 organic and 22 conventional equivalent food groups). A total of five factors were selected graphically considering the percentage of variation explained by the factors and thus accounted for 37% of the initial variability. By construction, none of these factors were correlated with each other. In order to identify groups of individuals with similar dietary changes, we carried out a two-step clustering procedure. First, a hierarchical ascending Ward's procedure was conducted. The graphical analysis of the dendrogram allowed to determine the existence of 6 distinct groups. Next, the groups were stabilized by means of a non-hierarchical classification of the K-means type. The procedure identified 6 clusters.

The 6 clusters were compared in terms of socio-demographic, lifestyles, and anthropometric characteristics using chi-2 tests. Difference in food intakes, nutrient intakes and nutritional scores were compared across clusters using ANOVA test with Tukey adjustment. For nutritional scores, a paired - Student *t*-test was used to compare scores at the two time points. For nutrient intakes and dietary indexes (PDI, hPDI, uPDI, PANDiet, plant to total protein ratio, PNNS-GS2), the residual method was applied to adjust for energy intake (Willett and Stampfer, 1986).

Next, the food purchase motives were analysed across clusters using ANOVA and ANCOVA. Three models were conducted. Model 1 was unadjusted, model 2 was adjusted for sex, age and educational level and model 3 was additionally adjusted for social desirability bias. ANOVA test with Tukey adjustment was used for model 1 and ANCOVA test with the same adjustment was used for model 2 and 3. All significant thresholds were set at 0.05. SAS 9.4 Software was used for all statistical analyses.

Table 1
Baseline sociodemographic, lifestyle and anthropometric characteristics across clusters (NutriNet-Santé study, n = 13,292, 2014).

Cluster	Towards plant and organic foods	Towards plant foods	Towards healthy foods	Towards healthy-plant foods	Towards animal foods	Towards unhealthy foods	Total	p[a]
	N = 1861 (14%)	N = 3099 (23%)	N = 1738 (13%)	N = 912 (7%)	N = 3604 (27%)	N = 2078 (16%)	N = 13292	
Sex, (%)[b]								***<0.0001***
Women	82.2	75.5	70.3	69.1	75.9	64.5	**73.7**	
Men	17.8	24.5	29.7	30.9	24.1	35.5	**26.3**	
Age, (%)[b]								***<0.0001***
18–35	9.6	6.2	9.0	9.2	7.8	7.0	**7.8**	
35–50	21.8	19.3	23.5	25.4	19.9	19.4	**20.8**	
50–65	44.8	43.5	39.7	42.1	40.6	40.3	**41.8**	
>65	23.9	31.0	27.7	23.2	31.7	33.3	**29.6**	
Occupational status, (%)[b]								***<0.0001***
Unemployed	3.9	3.0	2.3	3.7	3.6	3.6	**3.4**	
Never employed	5.6	5.0	6.3	6.0	5.3	4.6	**5.3**	
Self-employed, farmer	1.5	1.4	2.0	1.3	0.6	1.4	**1.3**	
Employee, manual worker	12.5	13.8	14.0	16.9	12.3	13.3	**13.4**	
Intermediate professions	15.6	13.3	14.7	14.7	13.5	11.9	**13.7**	
Managerial staff, intellectual profession	22.9	19.0	20.5	21.1	20.6	17.8	**20.1**	
Retired	37.9	44.6	40.3	36.3	44.1	47.4	**42.8**	
Education level, (%)[b]								***<0.0001***
Less than high-school diploma	18.8	24.7	21.7	23.2	20.6	26.8	**22.6**	
High school diploma	13.0	16.9	14.8	16.6	15.4	15.6	**15.5**	
Postgraduate	68.2	58.3	63.5	60.2	64.0	57.6	**61.9**	
Monthly income per household unit in euros, (%)[b]								***0.01***
<1200	8.8	9.4	9.8	11.7	8.3	10.2	**9.3**	
1200–1800	22.3	22.9	22.7	22.8	21.8	21.9	**22.3**	
1800–2700	28.5	27.1	27.7	29.4	28.3	29.7	**28.3**	
>2700	35.1	35.5	33.8	32.0	36.6	32.0	**34.7**	
Unwilling to answer	5.3	5.2	5.9	4.1	5.0	6.2	**5.3**	
Body Mass Index (kg/m^2), (%)[b]								***<0.0001***
≤25	71.1	64.1	63.6	58.4	66.9	57.6	**64.4**	
25–30	21.8	26.1	26.2	26.6	24.8	30.6	**25.9**	
>30	7.1	9.8	10.2	14.9	8.4	11.8	**9.8**	
Physical activity, (%)[b]								***0.02***
Low	16.8	17.8	19.0	20.5	18.6	18.7	**18.4**	
Moderate	37.1	35.1	38.8	33.1	36.8	34.6	**36.1**	
High	35.1	36.6	31.6	33.7	33.7	35.9	**34.6**	
Missing data	10.9	10.5	10.6	12.7	10.9	10.8	**10.9**	
Smoking habits, (%)[b]								***0.06***
Never smoker	48.3	50.7	49.5	47.3	50.5	47.1	**49.3**	
Former smoker	42.4	40.8	41.3	41.2	41.0	43.0	**41.5**	
Current smoker	9.3	8.6	9.3	11.5	8.5	10.0	**9.2**	
Social-desirability score (2 to 10)[c]	7.36 (1.35)	7.29 (1.34)	7.28 (1.37)	7.18 (1.33)	7.29 (1.35)	7.22 (1.34)	**7.28 (1.35)**	**0.01**

[a] p-values are based on Khi-2 test.
[b] Values presented are percentages.
[c] Values are means (SD).

3. Results

The two-step procedure allowed to identified 6 clusters which were named according the specificities as regards the response variables: “towards plant and organic foods” (14%), “towards plant foods” (23%), “towards healthy foods” (7%), “towards healthy-plant foods” (13%), “towards animal foods” (27%) and “towards unhealthy foods” (16%).

3.1. *Cluster description socio-demographic*

The socio-demographic characteristics by cluster are presented in Table 1. In the total population, there were more women than men (73.7%) with a mean age in 2014 of 56 years (SD = 12,7). *Cluster towards animal foods* and *Cluster towards plant foods* exhibited similar characteristics to the whole sample, except for income ≥2700 more frequent in *Cluster towards animal foods*. *Cluster towards plant and organic foods* included the highest proportion of women, 18-25-year old participants, graduates and people with a BMI below 25 kg/m2. *Cluster towards unhealthy foods*, in contrast, comprised the highest proportion of men, over 65 years old and less educated. *Cluster towards healthy foods* did not have any distinct socio-demographic characteristics. *Cluster towards healthy plant foods* had the highest proportion of individuals under 50 and with a BMI over 30. The range of the social-desirability score was similar across clusters with the highest mean score for *Cluster towards plant and organic foods* (7.36 SD = 1.35) and the lowest for *Cluster towards healthy plant foods* (7.18 SD = 1.33) (Table 1).

3.2. *Food consumption evolution*

Overall, for animal products, the consumption of dairy products, poultry, meat, and processed meat decreased between 2014 and 2018, while the consumption of fish and seafood, eggs, other fat increased. In terms of plant-based food, the consumption of fruit juices, refined grains and sugar-sweetened beverages decreased, and the consumption of the other groups increased. The consumption of alcoholic beverages decreased, while the consumption of non-alcoholic beverages increased. The consumption of sweets and desserts, other fatty, salty, and sweet products and dairy and meat substitutes increased (Supplemental Table 5).

Specifically, participants in *Cluster towards animal foods* consumed less animal-based food (lower consumption of dairy products and eggs) and less unhealthy plant-based food than other clusters in 2014 but have increased their consumption of animal-based food over time (excluding meat and processed meats). Participants in *Cluster towards plant foods*, which were similar to the overall average diet in 2014, have shifted to a more plant-based diet in 2018 (highest increase in wholegrain products and highest decrease in dairy products and fish). Participants in *Cluster towards plant and organic foods* had the highest consumption of most

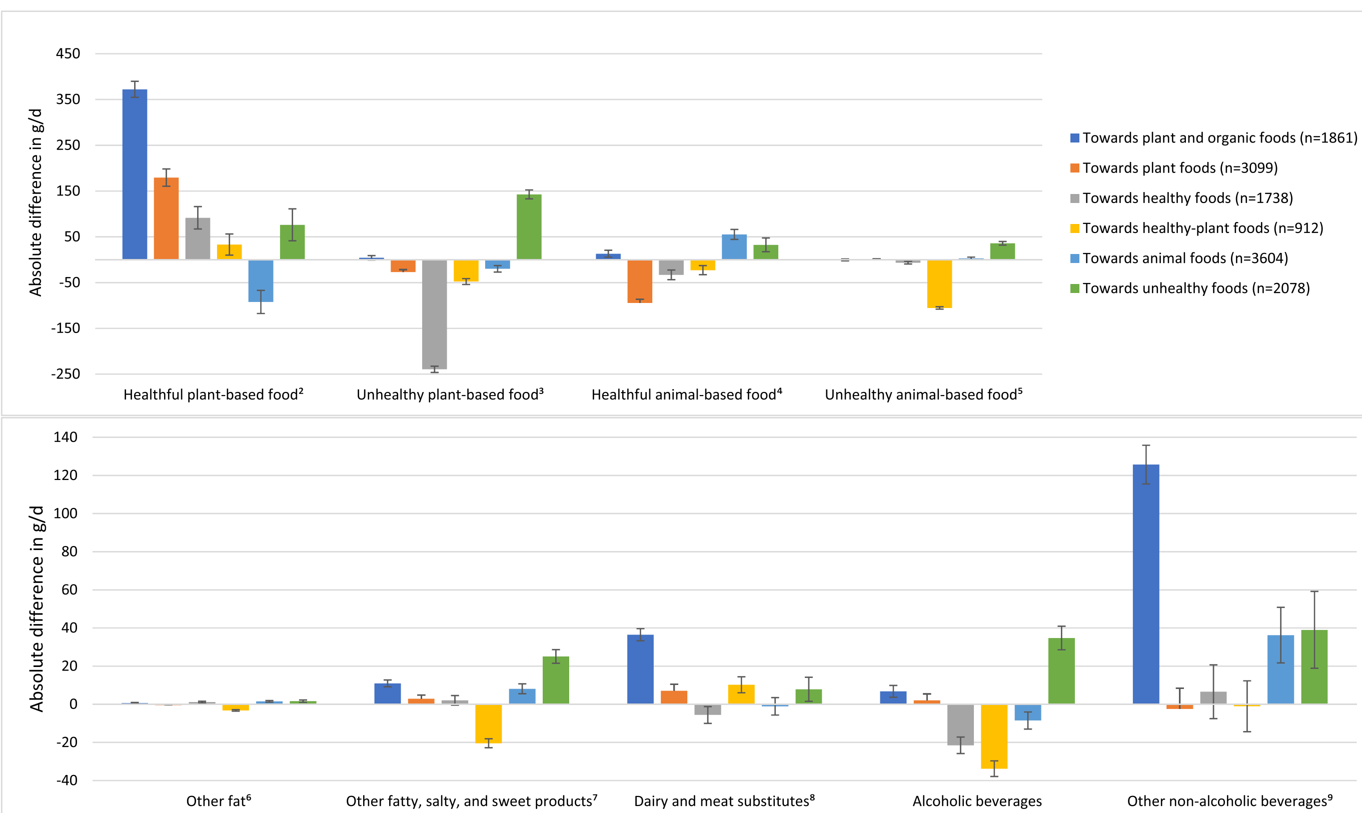

Fig. 1. Absolute differences over time (2018 vs 2014) of daily intake of the main food groups across clusters (NutriNet-Santé study, n = 13,292)[11] ANCOVA with Tukey's post-hoc test was used for testing differences between clusters
[2] Wholegrain products, vegetables, fruit, nuts, legumes, vegetable oils, coffee, tea
[3] Fruit juices, refined grains, potatoes, sugar-sweetened beverages, sweets, and desserts
[4] Fish, seafood, dairy, poultry
[5] Processed meat, red meat, eggs
[6] Butter, “mayonnaise” and cream
[7] Snacks, chips, salted biscuits, dried fruits, dressing, sauces, milky-desserts, and mixed dishes
[8] Soya-based products, soya milk plant-based cream
[9] Chocolate or chicory with milk, chicory, water, infusion, kombucha, non-alcoholic beer.. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

healthful plant-based products and further increased their consumption and the lowest consumption of alcohol, meat, processed meat, poultry, sweets and desserts and refined grains in 2014. Participants in *Cluster towards unhealthy foods* in 2014 had a low consumption of vegetables, nuts, seeds and legumes, fish, non-alcoholic beverages and in 2018 increased their consumption of fruit juices, refined grains, potatoes, sugar-sweetened beverages and sweets and desserts. Participants in *Cluster towards healthy foods*, which showed the highest consumption of unhealthy plant-based products in 2014, showed the most important decrease in 2018. Participants in *Cluster towards healthy plant foods*, who showed the highest consumption of sugar-sweetened beverages, poultry, processed meat, meat, eggs, other fat, other fatty, salty, and sweet products, alcoholic beverages in 2014, decreased their animal-based and unhealthy plant-based food consumptions over time (Fig. 1 and Supplemental Table 5).

Participants in *Clusters towards animal foods, towards plant and organic foods* and towards healthy plant foods increased their organic food consumption by 10%, 112% and 16%, respectively (Fig. 2 and Supplemental Table 6). *Cluster towards animal foods* participants mainly increased their consumption of organic animal-based products. *Cluster towards plant and organic foods* participants, showed strong increased of healthful and unhealthy plant-based products and animal-based products as organic while conventional ones decreased. Among *Cluster towards healthy plant foods* participants, consumption of organic products increased, except for unhealthy animal-based food (Supplemental Fig. 4). Participants in *Cluster towards plant foods, towards healthy plant foods and towards animal foods* decreased their organic food consumption.

Overall, the average of the dietary indicators was towards an improvement in nutritional quality (Supplemental Table 6). More specifically (Fig. 2), a high increase in daily energy intake was identified among participants in *Cluster towards unhealthy foods*, followed by those in *Cluster towards plant and organic foods*, while a high decrease was detected among participants in *Cluster towards healthy plant foods* which had the highest energy intake in 2014. All the participants decreased their uPDI (unhealthy PDI) score except those in *Cluster towards unhealthy foods* who increased it. Similarly, all the participants increased their cDQI and aDQI scores, to a varying degree, except those of *Cluster towards unhealthy foods*.

As shown in Fig. 2 (and Supplemental Fig. 5), participants in *Cluster towards animal foods*, had lower plant-based diet scores as illustrated by a decreased in PDI, hPDI, pDQI scores and vegetable protein ratio. On the contrary, participants in *Cluster towards plant foods* increased their plant diet scores. Participants in *Cluster towards plant and organic foods*, apart from PANDiet, moved towards a healthier diet, whether plant or animal foods (increase in aDQI as well as in the vegetable protein ratio), whereas *Cluster towards unhealthy foods* degraded in all these scores (except for PDI) which is unfavourable to sustainable diet. Participants in *Cluster towards healthy foods* showed a large improvement in the plant quality of

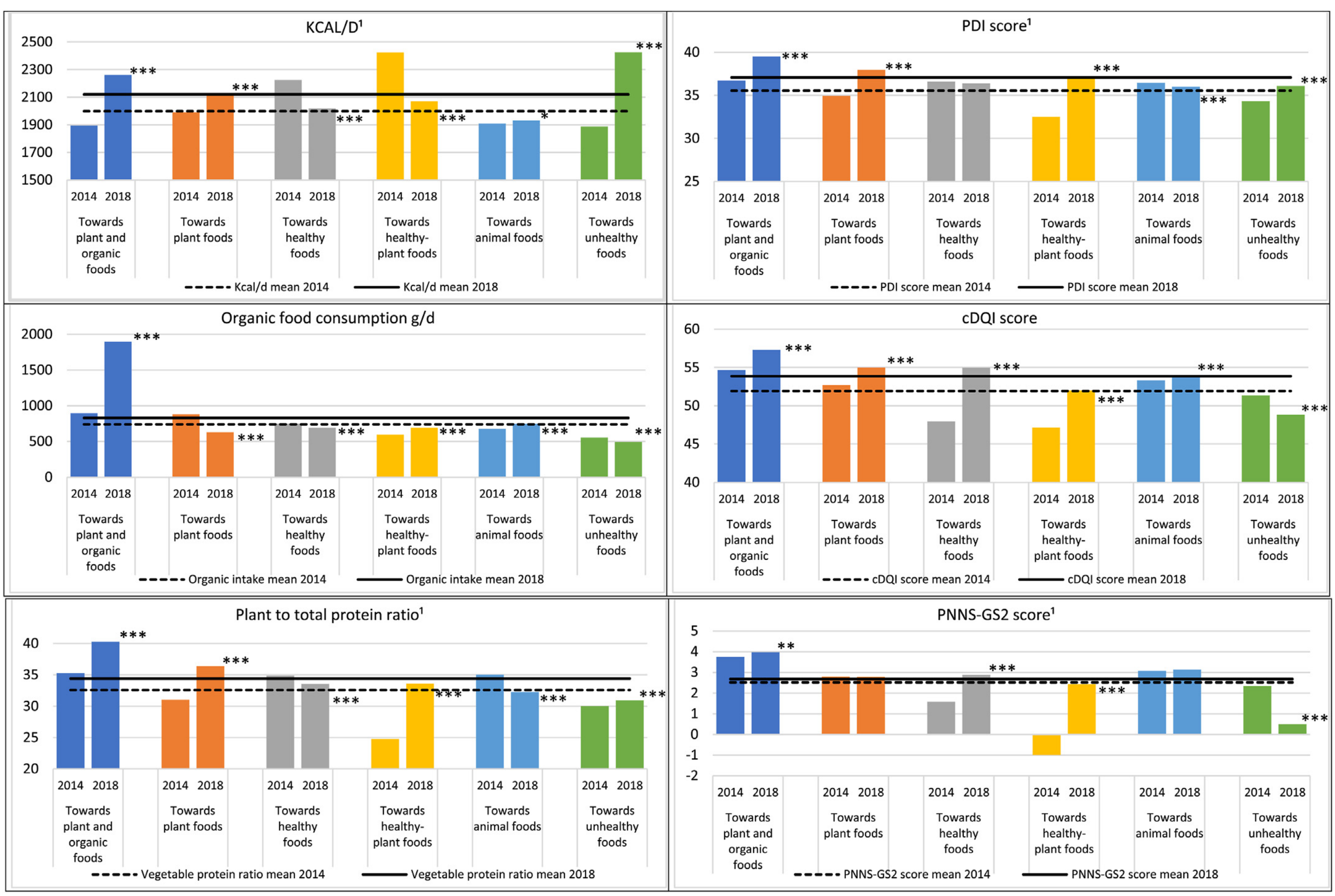

Fig. 2. Dietary indexes at baseline (2014) and in 2018 across clusters (histogram) and globally (curves) (NutriNet-Santé study, n = 13,292)
Abbreviations: cDQI: Comprehensive Diet Quality Index; PDI: Plant-based Diet Index; PNNS-GS2: Programme National Nutrition Santé-Guideline Score 2
[1] Values are adjusted with the residual method to adjust for energy intake
The 2014 and 2018 means denote the means of the study sample
* p-values <0.01. P-values are based on Student test for paired values comparing 2014 to 2018 data across clusters
** p-values <0.001. P-values are based on Student test for paired values comparing 2014 to 2018 data across clusters
*** p-values <0.0001. P-values are based on Student test for paired values comparing 2014 to 2018 data across clusters.

their diet. Participants in *Cluster towards healthy plant foods* improved all these scores, the majority being lowest in 2014. The PANDiet score decreased in all participants except those in *Cluster towards healthy plant foods*, which showed a low level in 2014.

3.3. Food purchases motives

Supplemental Table 7 compared food purchase motives across clusters. “Taste” was the predominant motive for all clusters with a minimum of 8.85 (average of participants in *Cluster towards unhealthy foods*), followed by “local and traditional production” and “absence of contaminants” with similar values. The lowest rated food purchase motive was “avoidance for environmental reasons” with a maximum of 3.14 (average of participants in *Cluster towards plant and organic foods*) followed by “innovation” with a maximum of 3.81 (average of participants in *Cluster towards unhealthy foods*). As regards environmental and health aspects, participants in *Cluster towards plant and organic foods* showed highest scores for both motives. Participants from *Clusters towards unhealthy foods* and *towards healthy plant foods* showed lowest scores for environmental aspects and participants in *Cluster towards healthy plant foods* had a significantly lower score for health than participants in *Cluster towards unhealthy foods*.

The hierarchy of food purchase motives was rather similar between clusters. However, “price” was at a higher level for participants in *Clusters towards unhealthy foods* and towards healthy plant foods, and “absence of contaminants” became less important for these 2 clusters compared to the other clusters. Compared to model 1, models 2 and 3 led to lower relative differences in food purchase motives across clusters, but the trends were similar (Supplemental Table 7).

Fig. 3 shows the relative differences in food purchase motives of participants across clusters using the total average as reference. As regards environmental motives, participants in *Cluster towards plant and organic foods*, and *Cluster towards plant foods* to a lower extent, had much higher concerns than the overall mean, more precisely for the “ethics and environment”, “local and traditional production”, “avoidance for environmental reasons”, “absence of contaminants” and “healthy and environmentally friendly consumption” motives. While participants of *Cluster towards healthy plant foods* had the lowest scores for these motives except for “local and traditional production” where participants of *Cluster towards unhealthy foods* had the lowest score. For the food purchase motive related to “health”, the ranking between clusters was similar to “ethics and environment” with the lowest mean for participants in *Cluster towards healthy plant foods*. For the food purchase motives such as “price”, “convenience” and “innovation”, participants in *Cluster towards unhealthy foods* had higher value than the overall population but “absence of contaminants” was also important.

4. Discussion

The purpose of this study was therefore to identify clusters of changes in consumption (in terms of nutritional quality, plant-based and organic consumption) and to analyse the association of these changes with their baseline purchase motives (with a focus on sustainable motives).

Our findings suggest that a part of the population (*Cluster towards plant and organic foods*) has already initiated a dietary transition towards sustainable diets (improve nutritional quality, increase plant-based food and organic food consumption). These participants were those who declared more often sustainable food purchase motives at baseline. However, another group (*Cluster towards unhealthy foods*) did not appear to have initiated a transition and is trending toward less sustainable diets. These participants had greater concerns about price and innovation than others.

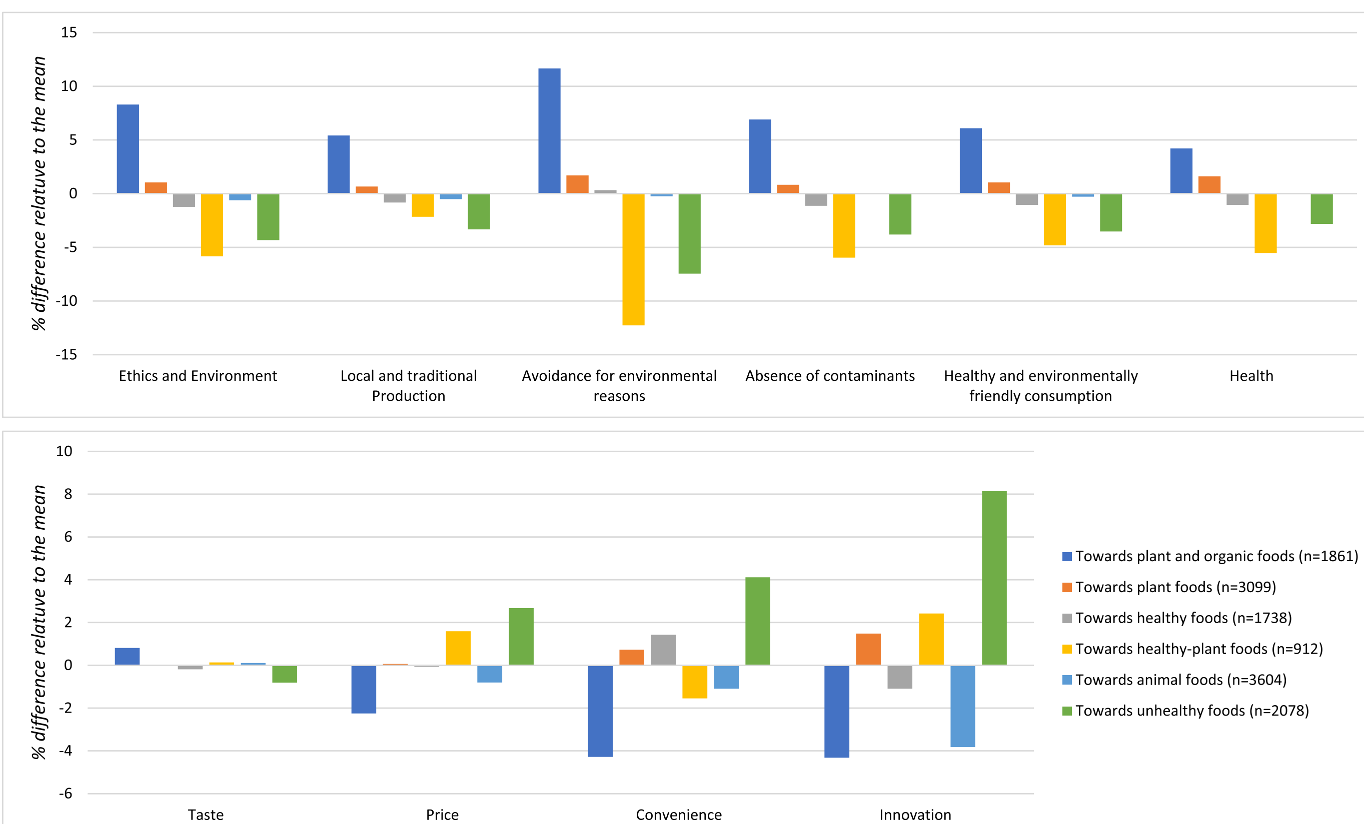

Fig. 3. Relative differences (as % based on the total mean) of food purchase motives scores across clusters (NutriNet-Santé study, n = 13,292, 2014) Food purchase motives scores are unadjusted.

4.1. Changes in food consumption

Overall, as we observed in a previous study (Brunin et al., 2021), diet quality, as expressed by various indicators, apart from the PANDiet, was overall improved over the 4-y period and the diets appeared more sustainable. Thus, plant-based and organic food consumption increased over time while meat, processed meat and sugar-sweetened beverages declined over time.

An increase in healthy plant-based products and a decrease in animal-based products compared to 2014 occurred for some specific clusters (*Clusters towards plant foods, towards healthy foods and towards healthy plant foods*). Nevertheless, although *Cluster towards plant and organic foods* participants slightly increased their intake of healthy animal products, they seem to be moving towards a more plant-based diet. Indeed, in 2014, they had the lowest consumption of animal-based products and the highest increase in healthful plant-based products over time. Previously, a cluster study carried out among 8302 participants showed that those with the lowest GHGe related to food production were those with highest healthy plant-based products consumption and lowest intakes of meat, soft drinks, and alcohol (Vieux et al., 2020). In addition, many studies have documented that the more animal products in a diet, the greater the impact on the environment (Aleksandrowicz et al., 2016; Garnett, 2011; Hallström et al., 2015; Poore and Nemecek, 2018; Tilman and Clark, 2014). All these findings suggest that dietary changes towards a more plant-based diet observed in our study can be interpreted as an initiation of a transition towards more sustainable diets. In addition to environmental benefits, a shift toward sustainability would lead to a reduction in mortality risk (Aleksandrowicz et al., 2016; Clark et al., 2019; Laine et al., 2021). We also recently observed that an increase in the PNNS-GS score, reflecting the level of adherence to the French food-based dietary guidelines, was associated with lower environmental pressures, illustrating potential co-benefits of adequate food consumption for human and planetary health (Kesse-Guyot et al., 2020).

It is noteworthy that participants in clusters consuming the least meat and processed meat were those consuming the highest quantity of dairy products and meat substitutes. As the consumption of the latter food category is growing rapidly in the general population (EUROPEAN COMMISSION, 2018), it would be important to quantitatively assess its impact on health and environment. Indeed, a life cycle assessment study showed that plant-based burgers (texturized wheat protein, coconut oil and potato protein) replacing beef steak would be beneficial in reducing GHG emissions, water consumption and land use compared to beef burgers (EUROPEAN COMMISSION, 2018). In addition, there is still a lack of data on the long-term health effects of certain protein-rich meat substitutes that are often processed or ultra-processed.

Regarding changes in organic consumption, Participants of *Cluster towards plant and organic foods* were those with the highest baseline consumption and the highest increase over the 2014–2018 period. As identified in this study, individuals who consumed more organic products were those who make overall healthier food purchases, particularly by consuming more plant-based foods (Eisinger-Watzl et al., 2015). Indeed, organic farming is often associated with the environment and health concerns (Barański et al., 2014; Baudry et al., 2019; Gomiero, 2018). Regarding the environment, organic plant and dairy products would result in lower GHG emissions than conventional products, however organic meat does no exhibit particular advantages when compared to conventional products (Pieper et al., 2020). Indeed, organic farming model is not a silver bullet for all indicators. Apart from considering production methods and dietary patterns, it would be interesting to have strategies to reduce food waste, to act on interdependencies between crops and livestock, and on human consumption in order to move towards food sustainability. Muller et al., for example, also predicted that switching to a 100 percent organic will result in greater land use and deforestation, resulting in a 20–30% increase in soil erosion (Muller et al., 2017). Agroecology could be a lever to some of these challenges (Eyhorn et al., 2019; Wezel et al., 2020).

Participants in *Cluster towards unhealthy foods*, in contrast, showed dietary changes towards unhealthy diet, with a drastic increase in consumption of unhealthy plant products, animal products and alcohol. Even if it is well documented that sweet products are not important GHG emitters, they are harmful for health and should be limited (Hjorth et al., 2020; Reinhardt et al., 2020). This group has the highest proportion of men and individuals over 65 years old. Our results are consistent with the literature as it was previously reported that women would be more prone to have a more sustainable diet than men and would tend to more reduce their GHG emissions, so that sex would be a determinant of environmental pressures related to diet (Biesbroek et al., 2019; Vieux et al., 2020). Regarding age and education, the results are less clear, with a decrease in meat consumption observed among the most educated, the oldest and the youngest people (Seconda et al., 2021; Tavoularis and Sauvage, 2018). In the study by Hjorth et al., GHG emissions (for 1000 Kcal) were the lowest and decreased the most among the oldest and least educated (associated with the decrease in animal products) while in the study by Mehlig et al. such association was showed among the youngest (25–34 years) and was not significant with education level. While for BMI, both studies showed similar results: i.e., GHG emissions were higher among individuals with a high BMI (with and without adjustment) (Hjorth et al., 2020; Mehlig et al., 2020). In our study, *Clusters towards unhealthy foods* and towards healthy plant foods, which had more animal than plant-based diet in 2014, had the most participants with a BMI >30.

4.2. Motives for food purchase

Since our collection on the more or less sustainable motives, new questionnaires have been developed illustrating the growing interest for these topics in a context of global environmental crisis (Verain et al., 2021). This present study is a longitudinal study that complements previous cross-sectional study on organic and conventional purchase motives (Allès et al., 2017). Taste has been identified as the most important motives in food purchases (Rejman et al., 2019) what is concordant with our findings, irrespective of the cluster. Price and health are also recurrent motives for consumers but this depended on social categories (Burlingame, 2012; Rejman et al., 2019; Steenhuis et al., 2011). Recently, sustainability has emerged as a novel concerns in food choices, mostly in regard to animal-based food consumption, for certain group of the population in many geographical areas (Tobi et al., 2019). Indeed, consumers who are more sensitive to environmental issues are also those who eat less meat (Vanhonacker et al., 2013). They may be more concerned about the origin of meat and then more sensitive to animal welfare (Clonan et al., 2015). In addition, a study conducted among 1083 participants showed that people who are more attracted to nature are more positive about the idea of a meatless meal (de Boer et al., 2013). Nevertheless, it has been shown that there is a gap between motive and actual sustainable consumption that is referred to as "the green gap" (Bennett and Williams, 2011).

Our results showed that more sustainable food consumptions (higher dietary indexes reflecting healthier diet, lower meat consumption and higher consumption of plant foods) were associated with specific sociodemographic profiles (more women, younger, and more educated) and also more sustainable food purchase motives. These findings are in line with previous cross-sectional studies. Indeed, different segments of the population differed as regards sustainable attitudes. For instance, men tended to consume more meat than women, due to cultural and social reasons (De Backer et al., 2020) and women were found to be more sensitive to sustainability concerns such as buying local meat or caring about animal welfare (Verain et al., 2015). Our results also showed that when the motive scores were also adjusted for sex, the scores decreased suggesting that sex can be a major factor. In addition, individuals with a high level of education consumed less meat and exhibited environmentally friendly food choice (de Boer et al., 2013; Tobi et al., 2019).

Interestingly, participants in *Cluster towards healthy plant foods* exhibited an unhealthy diet at baseline and initiated favourable changes between 2014 and 2018, suggesting potential awareness, as they had the worst sustainability-related motive scores. Of note, this cluster included only 7% of the sample. Participants in *Cluster towards unhealthy foods* (the cluster with the highest proportion of men, over 65 years old and less educated), degraded the quality of their diet in 4 years but were not concerned by sustainable motives and more interested in price, convenience and innovation motives than the other clusters. These individuals would not have started their dietary transition and should therefore be a major target of the action levers. However, an important aspect of sustainable foods are their potential higher monetary costs. Higher adequacy to nutritional guidelines and thus lower health and environmental impact was associated with a higher monetary cost (Kesse-Guyot et al., 2020).

Participants in Cluster towards plant and organic foods increased their organic consumption the most (already the highest at the beginning in 2014), and had the highest motives for environmental and health. Organic foods are often considered healthier and more environmentally friendly by consumers (Tobi et al., 2019) which constitutes the main motives for buying these products (Hoffmann and Wivstad, 2015). Nevertheless, an important barrier to purchase organic food is price (Rejman et al., 2019). Here, participants in *Cluster towards unhealthy foods* had the lowest consumption of organic products in 2018 and the highest motives related to price in 2014. In contrast, individuals who were less concerned by the price of food have a displayed interest for organic food and the environment (Tobi et al., 2019), as recovered in this study for participants in *Cluster towards plant and organic foods.*

4.3. Strengths and limitations

It is important to underline that this population was not representative of the general French population as the cohort includes volunteers, resulting in a sample with more women, older people, and more graduates as well as healthier diets (Andreeva et al., 2015) but allows to include a substantial number of participants who have initiated sustainable transitions. Individuals are more also aware of environmental and health issues as illustrated by the higher consumption of organic food (Baudry et al., 2019). Furthermore, the Org-FFQ questionnaire was self-administered, which may lead to an overestimation of food consumption (and organic food consumption) (Cade et al., 2002). However, the same pre-existing validated questionnaire was used at both points (2014 and 2018), allowing for an estimate of sustainable changes between the two points (Kesse-Guyot et al., 2010). It would be interesting in future studies to investigate the evolution of food purchase motives to determine if sustainable motives increase concomitantly with dietary changes and if there exists a temporality. We may hypothesize that participants who were most concerned with sustainable issues influenced their answers to questionnaire. Nevertheless, adjustment for desirability bias using a validated questionnaire did not modify substantially the findings. Finally, the studied period is of great interest since the area under organic farming has almost doubled between 2014 and 2018 in France (FIBL Statistics, n.d.). Moreover, we measured significant dietary changes during this short period, although longer-term investigations may be relevant.

However, 'external' factors not measured in the 2014–2018 period may have influenced individuals and their behaviour. Due to the many events and behaviours that influence eating patterns, longitudinal studies are not always able to fully identify their determinants (Biasini et al., 2021). Thus, marketing, and information campaigns, health incidents, the establishment of public health guidelines or a personal event, may also have an impact on behavioural change. However, it has been pointed out that health, sanitary communications with a preventive goal, would have counterproductive impact (Werle and Cuny, 2012). This study is the first to examine the relationship between actual dietary changes towards sustainable consumption at the individual level and pre-existing food purchase motives using a longitudinal design while considering two farming methods: conventional and organic as a model of agroecological farming. Furthermore, the cluster analysis allowed the identification of the subpopulation most inclined or not to a sustainable food transition.

In conclusion, in a context where a dietary transition is essential to achieving climate and resource preservation targets, we observed that some groups of this population, the most sensitive to sustainable food purchase motives, are changing their eating habits in favour of a more sustainable diet, but it also suggests that some population groups, with specific sociodemographic profiles, are not sensitive to this or are unable, at this stage, to initiate such transition. For example, to encourage behavioural changes, measures such as subsidies for healthy foods and taxes on unhealthy foods could be implemented, as well as the creation of mobile applications to help in guiding consumers towards more sustainable food choices. However, beyond consumer behaviours, it is noteworthy that social, economic, public policies, and environmental factors should be considered to promote more widely sustainable diet.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clrc.2022.100062.

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