# Stages of change toward meat reduction: associations with motives and longitudinal dietary data on animal-based and plant-based food intakes in French adults

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**Conflict of interest**

Anouk Reuzé, no conflicts of interest

Caroline Méjean, no conflicts of interest

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Benjamin Allès, no conflicts of interest

## Ethics approval and consent to participate

The NutriNet-Santé study complies with the Declaration of Helsinki guidelines and was approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB Inserm No. 0000388FWA00005831) and the French data protection authority (Commission Nationale de l'Informatique et des Libertés, CNIL No. 908450/ No. 909216). The study protocol is registered at ClinicalTrials.gov under the number NCT03335644. All subjects provided informed consent.

## Consent for publication

Not applicable

## Availability of data and materials

The datasets generated and/or analyzed in this study are secure under health data regulations set by the French data protection authority (Commission Nationale de l'Informatique et des Libertés, CNIL) and are not publicly available. The data are available upon reasonable request to the study's operational manager, Nathalie Druesne-Pecollo (n.pecollo@eren.smbh.univ-paris13.fr), for review by the NutriNet-Santé study steering committee.

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**Running title**

Stages of change and motives toward meat reduction

**List of abbreviations**

BMI: body mass index; PDI: plant-based diet index; SEM: standard error of the mean; SD: standard deviation; TEI: total energy intake; TTM: transtheoretical model.

## Abstract

**Background:** Reducing meat consumption is advocated for healthier and more sustainable diets. However, behavioral studies are needed to better understand the mechanisms underlying meat-reducing dietary changes.

**Objective:** The main aim of this study was to compare the motives associated with stages of change toward meat reduction in French adults, using the transtheoretical model (TTM). A second aim was to investigate the associations between stages of change and adherence to dietary patterns favoring a better balance of animal and plant food consumption over time.

**Methods:** This longitudinal study included 25,143 non-vegetarian participants of the web-based NutriNet-Santé cohort with a mean follow-up of 6.2 (SD = 2.6) years. Dietary data were obtained from 24-hour dietary records over the period 2009–2019. Contribution of meat to total energy intake and scores measuring the contribution of healthy and unhealthy plant-based foods to the diet were computed. A questionnaire completed in 2018 allowed us to identify the TTM stages of change related to meat reduction (precontemplation, contemplation, preparation, action, maintenance), and recorded motives related to meat consumption. We used multivariate linear mixed models for repeated data to assess associations between food intake changes and stages, and logistic regression for motives, presented as adjusted frequencies.

**Results:** Participants in late stages were characterized by a significantly higher decrease in meat intake over time, compared to the earliest stage (e.g., $\beta_{maintenance*time} = -0.08$, $p < 0.0001$), and a higher increase in the healthy plant-based food consumption score over time (e.g., $\beta_{maintenance*time} = 0.11$, $p < 0.0001$). Concerns about health, nutrition, and the environment were the most frequently cited motives for reducing meat consumption at all stages.

**Conclusions:** Individuals who had already initiated meat reduction adhered to healthier and more sustainable diets than meat continuers. Characterizing motives according to readiness to reduce meat consumption could support tailored public health campaigns.

**Clinical Trial Registry**

Clinical Trial Registry: NCT03335644

https://clinicaltrials.gov/ct2/show/NCT03335644

**Key words**

Longitudinal study; Epidemiology; Meat reduction; Transtheoretical model; Motives

**Highlights**

- Participants with higher levels of readiness were more likely to reduce their meat consumption for health, nutritional, and environmental motives than those with lower levels of readiness.
- Higher level of readiness to reduce meat consumption (i.e., action and maintenance stages of the TTM) was associated with a greater increase in healthy plant-based food consumption over time.
- Stages of change toward meat reduction were in line with observed changes in meat and meat product intakes measured by repeated 24 h dietary records.

## Introduction

One pathway for sustainable nutrition transition is a healthier balance of animal-based and plant-based foods. High meat consumption is associated with high environmental pressure (1), animal welfare issues (2), and adverse effects on human health (1). Dietary guidelines have been released in several countries to curb the consumption of meat and processed meat products (3–6). However, in most countries of the world, current levels of meat and meat product consumption remain above recommended ceilings for both human health and the environment (1,7,8). Even so, consumer intention to reduce meat consumption has recently increased (9,10). For example, in a recent study from the NutriNet-Santé cohort, we identified a shift toward more sustainable and healthier diets, in particular reduced meat consumption (11,12). More research is needed to gain a better understanding of how meat consumption is changing.

Emerging behaviors and the need to accelerate the sustainable food transition for as many consumers as possible call for a better understanding of how intention becomes behavior change. Studies focusing on behavior change have applied theories and models drawn from psychology and sociology to the question of meat reduction (13). Some theories, such as the theory of planned behavior, evaluate behavior change as a continuum process such as the theory of planned behavior (14–16). Others, such as the transtheoretical model (TTM) and the model of self-regulated behavior (16,17) view it as a sequence of discrete stages (18). The TTM is one of the most commonly used behavior change models in health (19) and defines behavior change as a sequence of five temporal stages of change, representing different levels of readiness, from a lack of awareness to intention and behavior change, based on past behavior and an action plan. These successive stages are (a) precontemplation (no intention of reducing meat consumption, no awareness of the adverse effects associated with eating meat), (b) contemplation (awareness of the adverse effects associated with eating meat,

intention to reduce meat), preparation (intention to reduce meat, action plan), action (recent modifications to meat consumption), and maintenance (long-term modifications to meat consumption) (18).

Though widely used, the TTM and stage-based models in general have been challenged (20–22). Some studies have criticized the stepwise modeling of the behavior change process, one stage following another, and its unidirectionality, which does not let an individual relapse into an earlier stage (14,23,80). The cut-off points on continuous variables (time and intention) defining stages of change have also been criticized for their arbitrariness (20,21). Even so, the TTM gives insights into the process of intentional behavior change and the scope of intervention (13,23). As meat consumption is frequently a norm in Western culture, changing it may require a conscious decision (24). Intention and actual behavior could conflict, and individual progress towards those stages that lead to behavior change needs to be studied (13).

To date, few studies have investigated the process of meat reduction across stages of change (13,25–28) and little is known about the link between the TTM for meat reduction and actual dietary intakes. A few cross-sectional studies have suggested that individuals in later stages of change consume less meat than those in earlier stages (13,26,27). However, these studies did not use validated food questionnaires and large-scale longitudinal studies to assess changes in food consumption across these stages. Also, in the context of sustainable food transition, to the best of our knowledge, no study has examined whether reducing meat consumption among non-vegetarians implies a shift toward a more plant-based diet over time.

To gain a better understanding of the process of behavior change, many studies have set out to identify factors influencing the reduction of meat consumption. Among these factors, several food choice motives have frequently been reported as inducing or hindering meat reduction, whether related to health (13,26,29–34), taste preferences (26,34), the

environment (13,26,29,30,34), animal welfare (26,30), or price (29,31–33). Social norms (13,26,33) and representations (33), and motives related to external factors, such as food convenience and accessibility (35) have also been described. Although many potential motives for and against meat reduction have been identified in the literature, few studies have investigated them in relation to individuals' levels of readiness to reduce their meat consumption (13,26). A recent Danish study has suggested that motives may vary across the stages of change toward meat reduction (13).

The main aim of this study was to compare motives for reducing or continuing meat consumption according to individual levels of readiness toward meat reduction in a population of non-vegetarian French adults. A secondary objective of this longitudinal study was to investigate the associations between stages of change and adherence to dietary patterns favoring a more desirable balance of animal-based and plant-based food consumption.

## Methods

### a. Study population

The NutriNet-Santé study is a web-based prospective observational French cohort study launched in May 2009 to investigate the relationship between nutrition and health, especially chronic disease risk, and the determinants of dietary behavior and nutritional status. Briefly, participants are Internet-using adult volunteers prospectively recruited among the general population. The study design is described elsewhere (36). It complies with the Declaration of Helsinki and was approved by the Institutional Review Board of the French Institute for Health and Medical Research and the French data protection authority (Commission Nationale de l'Informatique et des Libertés, CNIL 908,450 and 909,216). All the participants

signed an electronic informed consent statement. The ClinicalTrials identifier is NCT03335644.

### b. Self-reported reduction or continuation of meat consumption

A questionnaire on the motives and individual readiness for reducing consumption of animal-based foods in diet was developed, based on a previous questionnaire on food choice motives (37–39). It was built jointly by epidemiology, nutrition, and social marketing researchers. This non-mandatory questionnaire was sent in August 2018 to NutriNet-Santé participants. As meat, particularly ruminant meat, is a major concern for food sustainability and human health (1), we focused on changing consumption of meat, defined as beef, minced or roast steak, rib steak, stew, ground beef in a dish such as lasagna or spaghetti Bolognese, veal, lamb, pork, offal, breaded meat, game, rabbit or hare and all processed meats or derived products. This definition excludes poultry (turkey, chicken, duck, quail, pigeon). For detailed information about this questionnaire, see a previous study (34).

#### *Stages of change*

The questionnaire included a section on individual level of readiness to change meat consumption. Two questions classified participants into five groups corresponding to the five stages of change in the TTM (18). First, each participant was asked to pick one answer to the question: "*In recent years, have you reduced your meat consumption?*" from eight possible answers comprising five items related to the stages of change, and two items to include participants' situations outside the stages of change process. Participants who picked one of the five items related to stages of change were classified as follows: precontemplation stage ("*No, I don't see the point*"), contemplation stage ("*No, but I plan to do so soon although I don't know exactly how*" and "*No, but I've already considered doing so although I haven't changed my meat consumption*"), preparation stage ("*No, but I'm considering doing it soon*

*and I know how*"). Participants who gave a favorable response ("*Yes*") to the question were classified in one of the two subsequent stages, namely action and maintenance, and were asked a second question on how long they had been reducing their meat consumption, "*Could you please tell us roughly how long you've been reducing your meat consumption?*". In the TTM, the boundary between the action and maintenance stages is defined by how long ago the behavior change occurred; in the original model it was set at 6 months (18). However, many authors have criticized the arbitrariness with which this value was set (see for example (21)), and its inappropriateness in certain contexts, particularly dietary change (13,40,41). To choose the most appropriate boundary value for our context, we conducted sensitivity analyses based on how long ago the change in behavior occurred. We compared three lengths of time (less than 1 year, 1–2 years, more than 2 years) with the daily mean food intakes (in g/day). We observed significant differences between mean food consumptions for participants who made a change less than 2 years ago and those who did so more than 2 years ago. We therefore set the boundary at 2 years. Participants who answered that they had reduced their meat consumption for less than 2 years were classified in the action stage and those who had reduced their meat consumption for longer than 2 years were classified in the maintenance stage.

Participants whose responses did not correspond to any stage of change ("*No, it's for another reason*" and *"No, because I don't eat much meat anyway"*) were categorized in a group designated "other". Following the aim of this study, data for this group are not presented.

***Change-inducing and change-hindering motives toward meat reduction***

Participants were asked to respond to the following two statements by "*Yes*" or "*No*": "*I've reduced, or already thought about reducing my meat consumption*" (meat reduction) and "*I've always kept my meat consumption, I've never felt like reducing it*" (meat continuation).

For either reduction or continuation of meat consumption, a set of motives was proposed, including taste, health, environment, animal protection, and sociocultural influences (see all items in **Supplemental Table 1**). We used the literature to select motives in the questionnaire (30,42).

Motives: For each motive, participants who declared a change/continuation in their meat consumption were asked to rate their corresponding motives on a 5-point Likert scale, from "*Strongly disagree*" to "*Strongly agree*", including "*Neither agree nor disagree*", plus an "*I don't know*" answer. For example, participants who declared a reduction of their meat consumption, were asked to rate statements such as "*I care about animal welfare and the lives of animals*" or "*I think it's healthier not to eat too much meat*".

Change-inducing and change-hindering motives: If participants gave a favorable response to one motive ("*Somewhat agree*" or "*Strongly agree*"), a second statement "*and it encourages me to reduce my meat consumption*" was proposed to assess whether this motive induced a change in consumption, on a separate 5-point Likert scale. Similarly, for meat continuation motives, a second statement "*and this is one reason why I'm not reducing my meat consumption*" was proposed to assess whether this motive hindered a change in consumption.

Both Likert scales, for the motive and for the change-inducing or change-hindering motive, were then recoded to compute agreement scores ranging from 0 to 5 and from 1 to 5, respectively.

Using the same method as described previously (34), participants were then classified into three groups representing different types of motive, based on their answers to each motive:

- "No motive": Participants were considered to have "no motive" if they gave an unfavorable response ("*Strongly disagree*", "*Somewhat disagree*", "*Neither agree nor disagree*" and "*I don't know*") for the motive.

For participants in this group, the motive related to animal welfare was thus not felt to be important.

– "Motive, not change-inducing": Participants with a "motive, not change-inducing" were those who gave a favorable response ("*Strongly agree*" and "*Somewhat agree*") to the motive but an unfavorable one ("*Strongly disagree*", "*Somewhat disagree*", "*Neither agree nor disagree*") to the statement that the motive had induced a change in consumption.

  For participants in this group, the motive related to animal welfare was thus felt to be important but was not declared as change-inducing.

– "Change-inducing motive": Participants who gave favorable responses to both sets of statements were considered as having a "change-inducing motive".

  For participants in this this group, the motive related to animal-welfare was thus felt to be important and did lead to a change.

Similarly, for each motive related to meat continuation, participants were classified into three groups representing different types of motive: "no motive", "motive, not change-hindering", "change-hindering motive".

### c. Dietary data

***Dietary intake assessment***

Dietary data were collected through web-based, self-administered 24 h dietary records using validated tools (43,44). At baseline and every 6 months, participants were asked to provide three non-consecutive-day 24 h dietary records (here, the term "follow-up" refers to each time that the three dietary records were completed). These three records were randomly assigned over a two-week period (two weekdays and one weekend day) to take into account the intra-variability of the daily intake. The dietary assessment method took a meal-based approach,

reporting all foods and beverages consumed at any eating occasion. After filling in names of all food items, portion size for each item was estimated using standard measurements or photographs from a validated picture manual (45). Mean daily quantities of food groups (in g/d for solid and mL/d for liquid) were calculated from 24 h dietary records, weighted according to the day (week or weekend) for each follow-up. Energy, macronutrient and micronutrient values from the dietary questionnaire were estimated by the NutriNet-Santé food composition table listing more than 3500 different foods (46).

Food and beverages were classified into 12 plant-based and 6 animal-based food groups considering nutrients and culinary similarities, as developed by Satija et al. (47), and was adapted for the NutriNet Santé database to match French consumption habits more closely (48) (**Supplemental Table 2**). Owing to the increased diversity of plant foods consumed, we also estimated intakes of the following food groups: "Plant-based drinks" (e.g., soy, almond, or rice), "Miscellaneous plant-based food" including subgroups such as "Meat and processed meat substitutes" (abbreviated "meat substitutes"), "Dairy dessert and cheese substitutes" (abbreviated "dairy substitutes") and "Fermented or coagulated foods" (e.g., tempeh, tofu), and "Uncooked cereals and seeds" (e.g., oatmeal, sesame seeds). Three indices including the contribution of meat, processed meat, and meat products to total energy intake were also computed.

***Plant-based diet indices***

The three plant-based diet indices developed by Satija et al. were used to assess the contribution of plant-based foods to the diet (47). These indices measure the impact of plant-based foods on health: the plant-based diet index (PDI), the healthy plant-based diet index (healthy PDI) and the unhealthy plant-based diet index (unhealthy PDI). These indices were computed based on the consumption of the 18 food groups (12 plant-based foods and 6 animal-based food groups) mentioned above. For each food group, the participants' intakes

were classified into quintiles. The 18 food groups were classified into three categories according to their source (animal or plant) and nutritional quality: healthy plant-based foods, unhealthy plant-based foods, and animal-based foods. For a given individual, a sub-score for each of the food groups was assigned based on the category of the food group and the quintile of consumption of the food group. The sub-scores for the 18 food groups were then summed to obtain the final scores (range 18–90). To compute PDIs, positive scores were given to the healthy and unhealthy plant-based food categories (score of 1 for the first quintile and score of 5 for the fifth quintile) and reverse scores to animal-based food category (score of 1 for the fifth quintile and score of 5 for the first quintile). The same method was used for healthy PDIs, with positive scores for healthy plant-based food groups and reverse scores for unhealthy plant-based food and animal-based food groups, and for unhealthy PDIs, with positive scores for unhealthy plant-based food and reverse scores for healthy plant-based food and animal-based food groups. A higher PDI thus reflected higher consumption of plant-based foods and lower consumption of animal-based foods compared to the sample. A higher healthy PDI reflected higher consumption of healthy plant-based foods. A higher unhealthy PDI reflected higher consumption of unhealthy plant-based foods.

**d. Sociodemographic, anthropometric, and lifestyle data**

At baseline and once a year thereafter, participants were invited to fill out a set of self-administered questionnaires on sociodemographic, anthropometric, and lifestyle characteristics. For this study, characteristics collected closest to the questionnaire on changes in meat consumption were used. Data collected included sex, age, occupational category (unemployed/self-employed, farmer, employee, manual worker/intermediate profession/managerial staff, intellectual profession/no occupation) corresponding to their last occupational category before retirement, educational level (none or primary/secondary/undergraduate and others/postgraduate), household composition (alone

without children/alone with at least one child/two adults living as a couple without children/ two adults living as a couple with at least one child/two or more adults without children), size of urban residence unit (rural/<20,000 inhabitants/20,000–200,000 inhabitants/>200,000 inhabitants). Monthly income per household unit was obtained per household consumer unit (c.u.). One c.u. was assigned to the first adult in the household, 0.5 c.u. for other persons aged 14 or older and 0.3 c.u. for children under 14. Five categories were defined and were assigned to participants: <1200 € per c.u./1200–1800 € per c.u./1800–2700 € per c.u./>2700 € per c.u./refused to declare). The date of the most recent weight-loss diet followed was collected, and individuals were classified into three groups: no weight-loss diet, <5 years, >5 years. Self-reported height and weight measurements were collected. Body mass index (BMI) was calculated as weight (kg) per height squared ($m^2$), and participants were classified into three categories, according to World Health Organization (WHO) criteria: underweight (<18.5 kg/$m^2$), normal (18.5–25 kg/$m^2$), overweight (excluding obesity) (25–30 kg/$m^2$), obese (≥30 kg/$m^2$) (49). Self-reported height and weight measurements were validated against clinical measurements (50). Level of physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) (51), and three categories were defined.

### e. Statistical analysis

We included participants who had dietary data at least at two different follow-up times, from their inclusion in the cohort study until 6 months after the questionnaire on changes in meat consumption (included between 2009 and 2019). In addition, only follow-ups with two or three 24-hour dietary records were considered. Self-reported vegetarians and vegans together with those declaring they had eaten no meat in recent years were excluded from the study ($n$ = 3162), giving a final sample of 25,143 participants. More details of selection criteria can be found in the flowchart (**Supplemental Figure 1)**.

***Sociodemographic, anthropometric, and lifestyle characteristics***

Sociodemographic, anthropometric, and lifestyle characteristics were described in the total sample and compared across groups of individuals corresponding to stages of change using chi2 and ANOVA tests.

***Food consumption***

We collected all dietary data from each complete follow-up over the period from inclusion in the cohort study until 6 months after the questionnaire on changes in meat consumption. For each follow-up, we computed mean daily food consumptions based on available 24 h dietary records, together with the six dietary indices in relation to animal-based and plant-based food consumptions: daily mean contributions of meat, processed meat, and meat products to total energy intake, PDIs, healthy PDIs, and unhealthy PDIs. For each follow-up, PDIs, healthy PDIs, and unhealthy PDIs were calculated according to the consumption quintiles of the dietary data collected in 2009 and 2010.

First, we compared the mean daily consumption of meat, processed meat and meat products at inclusion and at the latest follow-up available for each participant, for the five stages of change.

Secondly, we assessed the mean daily food consumption over the period 2009–2019 by computing the average of the mean daily food consumptions of each follow-up. These means were adjusted for sex, age, and total energy intake for the mean daily food consumptions and mean PDIs, healthy PDIs, and unhealthy PDIs, and for sex and age for the mean daily contributions of meat, processed meat, and meat products to total energy intake using linear regression models.

The above two analyses included adjustments to correct potential estimation bias but did not include comparison tests. Accordingly, we conducted additional analyses using multivariate linear mixed models. These models were run to assess the association between the six dietary indices related to animal-based and plant-based food consumptions in the diet

over time (as outcomes) and stages of change (as the main explanatory variable, with the precontemplation stage as reference). This approach provides a more robust assessment of potential changes in dietary behaviors over time. Mixed models for repeated measures were used (PROC MIXED in the statistical software SAS®), with dietary indices as fixed effects, and intercept and time as random effects. In our analysis, the variable "time" refers to the length of time between the completion of the baseline dietary questionnaire and the completion of another questionnaire during the follow-up. The value of "time" corresponds to the date on which the baseline dietary questionnaire was completed. Given the non-normal distribution of the contributions of meat, processed meat, and meat products to the total energy intake, logarithmic transformations (Napierian) were computed and used as normalized dependent variables in the three corresponding models. The beta coefficient for stages of change represents the difference between the dietary index of a given stage and the precontemplation stage of change (reference) at baseline. The beta coefficient for stages of change × time interaction represents the difference in slope between the curve representing the dietary index over time for a given stage of change and the curve for the reference stage of change. Models were adjusted for sex and for characteristics collected closest to the questionnaire on changes in meat consumption, including age (continuous), educational level, number of follow-up times at which dietary data were recorded, monthly household income classes, occupational category, household composition, size of urban residence unit, BMI category, date of most recent weight-loss diet and physical activity level. Models for PDI, healthy PDI, and unhealthy PDI were also adjusted on the total energy intake, collected at the latest available follow-up. Models for contribution of meat, processed meat, and meat products to the total energy intake were run on the total sample, excluding participants who did not consume the food product measured by the index.

***Motives related to meat reduction and meat continuation according to stage of change***

In contrast to an earlier study conducted by our group (11), we used new variables of motives for meat reduction or continuation using the dedicated questionnaire previously described in the methods, and also described elsewhere (34). In this study, motives for reducing meat were described in the contemplation, preparation, action, and maintenance stages, and motives for continuing meat consumption were assessed for the precontemplation and contemplation stages.

For each motive, we ran multivariable logistic regression models between the groups representing different types of motive (no motive; motive, not change-inducing/hindering; change-inducing/hindering motive) and the stages of change. These models were adjusted for sex, age, educational level, monthly household income classes, occupational category, household composition, size of urban residence unit, BMI, date of most recent weight-loss diet and level of physical activity. We then computed the adjusted percentages from these regression models and for either meat reduction or meat continuation, adjusted frequencies of the three groups representing different types of motive were described according to stage of change.

All tests were two-sided, and a *p*-value of $<0.05$ was considered significant. Statistical analyses were conducted with SAS® (version 9.4, SAS Institute, Inc.) and some of the figures were made with R Studio® (version 3.6.2, RStudio, Inc).

## Results

### a. Sample selection and description

A total of 25,143 participants were included in this analysis. Characteristics of the sample are given in **Table 1**. Women made up 74.8% of the sample. Mean age at date of completion of the meat consumption questionnaire was 56.4 years (Standard Deviation (SD) = 13.8). More than 70% of the participants were at least undergraduate level, two-thirds belonged to an

438 occupational category corresponding to a higher socioeconomic position (e.g., managerial
439 staff), and a third reported a monthly income per household above 2700 € (Table 1). More
440 than 60% of participants were in one of the two last stages (action and maintenance)
441 (Table 1).
442 Sociodemographic, anthropometric, and lifestyle characteristics were compared according to
443 the five stages of change. Participants in the precontemplation stage included the highest
444 proportion of men, whereas we observed the highest proportion of women in the action stage
445 group. We also observed a higher proportion of older individuals in the precontemplation
446 stage, whereas the contemplation stage group included a higher proportion of younger
447 individuals. Participants in the maintenance stages included the highest proportion of
448 individuals with high educational level. Participants in the preparation stage included the
449 highest proportion of individuals with lower physical activity whereas the maintenance stage
450 included the highest proportion of participants with high level of physical activity (see
451 **Supplemental Table 3** for detailed results).

452 **b. Dietary intakes and indices of healthy and unhealthy plant-based diets according**
453 **to stage of change**

454 Over the period 2009–2019, the median number of follow-up times at which dietary data were
455 recorded was 7 and the mean follow-up period was 6.2 (SD = 2.6) years.
456 Regardless of the stage of change, participants consumed less meat, processed meat,
457 and meat products, comparing consumptions at baseline and at the latest available follow-up
458 (except for processed meat in the preparation stage) (**Figure 1, A**). Mean consumption of
459 meat, processed meat, and meat products gradually decreased between groups from the
460 precontemplation to the maintenance stage, at both inclusion (e.g., for meat, 57.5 (SD = 47.0)
461 g/day for precontemplation stage vs. 41.3 (SD = 40.1) g/day, for maintenance stage) and at
462 the latest available follow-up (e.g. for meat, 51.4 (SD = 46.4) vs. 33.2 (SD=37.0) g/day,

respectively). For more detailed results for dietary intakes among consumers, see **Supplemental Table 4**.

Over the follow-up period, the adjusted mean daily contributions of meat products, meat, and processed meat to total energy intake gradually decreased between the groups, from precontemplation stage to maintenance stage. Adjusted mean PDI and healthy PDI gradually increased between the groups (for PDI, 47.6, for precontemplation stage, and 51, for maintenance stage; for healthy PDI, 52.7 and 56.3, respectively), while unhealthy PDI was progressively slightly lower (respectively, 58.5 and 56.8) (**Supplemental Figure 2**). We also observed higher consumptions of meat and dairy plant-based analogues (e.g., soy or almond milk, plant-based patties, tofu, etc.) in later stages of meat reduction (see Supplemental Figure 2).

**c. Evolution of meat intakes and of the contribution of healthy and unhealthy plant-based foods to the diet, according to stage of change**

At baseline, there was a significant association between the action and maintenance stages and a smaller contribution of meat products to the diet, compared to the precontemplation stage (**Supplemental Table 5**). Only later stages were significantly associated with the slope of meat, processed meat, and meat product consumptions over time, meaning that only these participants showed a higher decrease in their consumption of meat products over time, compared to those in the precontemplation stage (**Figure 1, B**).
Stages of change toward meat reduction were all statistically associated with higher scores of PDI and healthy PDI at baseline, compared to the precontemplation stage (**Supplemental Table 6**). Only the last two stages were significantly associated with the slope of PDI and healthy PDI over time, compared to the precontemplation stage (Figure 1, B). The action stage was statistically associated with a higher contribution of plant-based foods over time and a higher contribution of healthy plant-based food over time, compared to the

precontemplation stage. For the maintenance stage, we also observed a statistically higher contribution of overall plant-based food and healthy plant-based food over time. At baseline, the contribution of unhealthy plant-based food to the diet was statistically lower for participants in the contemplation, preparation, action, and maintenance stages, compared to those in the precontemplation stage.

Finally, no significant association was observed between the four stages of change and the slope of unhealthy PDI over time.

### d. Motives for meat reduction and meat continuation according to stage of change

***Motives for meat reduction***

Concerns about health, nutrition, and preservation of the environment were the motives most frequently declared for reducing meat consumption by participants in the contemplation, preparation, action, and maintenance stages (**Table 2**). Frequencies of participants declaring these motives as change-inducing were even higher between the early and the later stage of change (e.g., for the health motive, 51% for contemplation vs. 75.3% for maintenance in the "change-inducing motive" group). In addition, some motives were felt to be important, but were less frequently declared as encouraging meat reduction in every stage of change. For example, up to 65% of participants in each stage declared they had concerns about animal welfare (participants in "motive, not change-inducing" and "change-inducing motive" groups). However, this motive was declared to have induced meat reduction in fewer than half of participants in all stages (33.1% for contemplation and 47.4% for maintenance, in the "change-inducing motive" group). Also, fewer than 10% of the participants declared motives such as aversion to the taste of meat or doctor's advice as change-inducing.

***Motives for meat continuation***

In both the precontemplation and contemplation stages, the pleasure of eating meat was frequently reported as a motive to continue meat consumption (73.9% and 67.1% for the precontemplation and contemplation stages, respectively, corresponding to the "change-hindering motive" group) (**Table 3**). Other motives such as thinking that meat is a good source of protein (64% and 53.4%), and that meat is part of personal culture (49.7% and 53%) were also fairly frequently declared as motives for not reducing meat consumption. Participants in the precontemplation stage frequently declared that they continued their meat consumption because they thought meat had health benefits (63.6%). Participants in the contemplation stage frequently declared that they continued their meat consumption owing to difficulty changing their meat-eating habits (51.5%).

## Discussion

Concerns about health, nutrition, and the preservation of the environment motivated individuals to reduce their meat consumption. Liking meat seemed to be one of the main barriers to change. Being in later stages of change toward meat reduction was associated with a higher decrease in the consumption of meat products and a higher increase in the consumption of healthy plant-based foods over time. To the best of our knowledge, this study is the first to examine the association between quantitative measures, which represent an evolution of food intakes, and the TTM, and to investigate a phase model of behavior change related to meat reduction in the French population.

According to the principles of the TTM applied to meat reduction, individuals in the two last stages of change (action and maintenance) had already started to reduce their meat

consumption. Observed meat intakes over time were consistent with self-reported intentions and behavior change, supporting the use of this TTM construct.

We observed that individuals who had already started to reduce their meat consumption consumed more plant-based foods, and especially healthy plant-based foods, than animal-based foods over time, compared to those who had no intention of changing their consumption (i.e., the precontemplation stage). Previous data in the same cohort study, using food frequency questionnaires and general food choice motives highlighted a slight trend towards healthier and plant-based diets over time in some parts of the population (12), notably in individuals with sustainability food concerns (11).

In our study, we found that concerns for health and nutrition were the main effective motives for reducing meat consumption for participants in contemplation through to maintenance stages. These two motives have been widely cited by meat reducers in previous studies (52), and even more among individuals in later stages (53). Yet the same two motives were also declared by participants who continued their meat consumption at the earlier stages of change, especially in the precontemplation stage. This in line with other studies which found that these motives were strongly expressed by meat eaters (31,53–55), for example those in the precontemplation stage (26,30). This paradox or ambivalent role of health and nutrition-related motives has been described previously (31,56,57) and may be partly explained by the evolution of messages derived from dietary guidelines over the last 20 years. These messages have evolved from encouraging meat intake in the early 2000s, to discouraging red meat and processed meat in the late 2010s and setting recommended ceilings (4).

Among change-inducing motives, preserving the environment was also frequently declared as a reason for reducing meat consumption, particularly in the later stages. This finding is in line with the recent Danish study (13), although previous studies have reported heterogeneous results (9,29,31,58). Public health campaigns combining health and environmental impacts of meat in their messages could thus be an effective strategy for encouraging meat reduction compared to a message focusing on a single motive, as suggested by a previous British study (59).

Concern for the preservation of animal life and for animal welfare was declared with moderate frequency as having induced meat reduction, compared to the previously cited motives. Animal welfare may be a stronger lever in other cultural settings (60) and especially for vegetarians or vegans (61), but we lack results on the effectiveness of this motive in reducing meat consumption in non-vegetarian populations. An intervention study highlighted that information about animal welfare had a strong effect on reducing meat consumption in Germany (55). To provide information about animal welfare, front-of-pack labels were developed (62), but are seldom available on food products in many countries including France. Few results are available on the effectiveness of such labels in influencing food choices (63), but further studies could investigate whether such information can incentivize meat reduction.

Among change-hindering motives, enjoying meat was the main motive reported by participants for continuing their meat consumption. This motive was even more often stated by consumers who had no intention of changing their consumption (precontemplation stage). Many previous studies have shown that the sensory attributes of meat, and in particular its taste, were a main lever of meat consumption (54,64), and so formed an important disincentive to meat reduction (61,65). Furthermore, in our study, food habits and culinary traditions seemed to hinder change in meat consumption, especially among individuals who

declared their intention to reduce meat (contemplation stage), as previously described (53). As the pleasure of eating is a core value of French food culture, public health authorities could also promote messages following the "less but better" principle (66), that is to say eating less animal-based foods both in quantity and frequency, but choosing those with better overall quality: fair trade, organic, or short circuit supply. To reduce their meat consumption, individuals could replace animal-based dishes by plant-based dishes in their meals, assuming they have the cooking skills and ideas for plant-based food recipes (67). Public health authorities could provide practical advice such as shopping tips, weekly meal planning, and recipes to help consumers add plant-based meals to their food habits such as the "*La Fabrique à menus"* in France (68)). Tasty plant-based products such as legumes could also be promoted, in line with previous findings (34).

Our study has some limitations. The study population consisted of volunteers, registered to answer questionnaires related to health and nutrition. This population might therefore have been more aware of health and nutrition issues. Although over 60% of the participants declared they had initiated a reduction in meat consumption, the mean intake of meat remained similar to national representative surveys (69). Another limit is the over-representation of women in our study sample compared to the general population (70), as commonly observed in various epidemiological studies (70), possibly producing selection bias. This over-representation could mean an over-representation of individuals reducing or willing to reduce their meat consumption, as it is well-established that sex is associated with changes in meat consumption (52,71). Nevertheless, our study offers the advantage of a large sample size, with over 25,000 participants, enabling us to identify a diverse range of meat consumption behaviors. Besides those who reduced their meat consumption, we identified more than 6,000 participants who reported continuing their meat consumption, of whom

51.8% reported no interest in reducing meat. Our analysis was controlled for sociodemographic characteristics, including sex, which helps limit this bias.

Secondly, some limitations regarding the use of the TTM can be highlighted, such as the arbitrary boundary between the action and maintenance stages, set at 2 years in this study. These stages are distinguished by the length of time since the behavior change occurred, which can be difficult to define in specific contexts, especially for food behavior (13,40,41). In addition, the definitions of contemplation and preparation stages is heterogeneous in the literature (13). For this study, we defined these stages in line with both the original definition of the TTM and the study of Tobler et al. (30). We note that the use of different thresholds and the variability of definitions in different studies make comparison between findings difficult and so might limit the external validity of our results.

Our study design did not enable us to study the characteristics of individuals who had reduced their meat consumption, but no longer do so, compared to those who were still reducing their consumption. Further research could address this topic.

Some authors have questioned the validity of the stages of change, suggesting that finer distinctions within stages may be relevant (72). For example, some authors have suggested subcategories for the precontemplation stage, such as “aware” and “unaware” (73). However, as claimed by one of the original authors of the TTM, the purpose of this model is not to identify a rigidly defined set of stages and prove their existence, but rather to improve our understanding of the process of behavior change and the scope to influence this process (23). Future longitudinal studies could explore diverse decision-making paths.

Thirdly, as suggested by the TTM, the process of change involves an individual going through successive stages toward behavioral change. However, this model might not fully capture the complexity of behavior change, as some individuals may skip a stage or stay in one (23,74), or regress to an earlier stage (75). Further studies assessing stages at different time points

could specifically explore relapse and other dynamics of the process. However, we observed that stages of change were in line with longitudinal dietary data. Our results support the use of such a model, although we acknowledge that this approach can be completed by other models of food behavior change.

Our study has several strengths. First, only a few studies in the literature have used the TTM to explore the process of meat reduction in a large population (13,26–28) or to explore the motives for meat reduction or continuation in the general population (13), although our sample may not be fully representative of the French population.

The longitudinal design of our study to explore the evolution of food consumption is another strength. It enabled us to observe changes in meat and meat product consumption over time using validated dietary questionnaires, and to evaluate the nutritional quality of diets across different stages of meat reduction. Further studies on the trajectory of other types of meat, such as poultry, could provide more information on the sustainable food transition. In the literature, certain studies suggest that meat reduction starts with increased poultry consumption (76–78), but other studies, in line with our cross-sectional findings, indicate a steady poultry consumption (31,76,78).

Another key strength of our study is that it examines the reduction in meat consumption in the specific context of France, where meat is central in the food culture (79). Meat reduction is thus highly relevant to a sustainable food transition in France. Transitions toward meat reduction may vary across different countries with different cultural and culinary backgrounds (28,80), which limits the comparison of the results. Our study may provide knowledge about Europeans who are less reluctant to reduce meat consumption, as more than 60% declared they were reducing their consumption, whereas in other studies, such as Denmark, only 27,6%

of participants did so (13). Country-specific studies are thus essential to ensure the relevance and robustness of results for sustainable food transition.

### *Conclusion*

In this study, longitudinal dietary data were in line with theoretical assumptions of the TTM, individuals who had already initiated a meat reduction adhering to healthier and more sustainable diets, as defined by the stages of change. Health, nutrition and environmental concerns were associated with reduced meat consumption. Enjoying meat hindered meat reduction, indicating an opportunity to provide advice and practical tools to enhance the attractiveness of plant-based foods, particularly in specific populations who do not yet feel concerned by meat reduction. Further studies quantifying the environmental impacts of diets could evaluate their contributions to enhance the current nutritionally sustainable transition.


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### Statement of authors' contributions to the manuscript

SH, CM, MT, SP, BA, EKG and NDP designed and implement the cohort study; BA, CM, LS and AR designed research and provided essential materials; AR and BA analyzed data or performed statistical analysis; AR drafted the paper; BA had primary responsibility for final content. All the authors have read and approved the final manuscript.

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Table 1. Sociodemographic, anthropometric, and lifestyle characteristics of included participants and stages of change, NutriNet-Santé, 2009–2018, *n* = 25,143

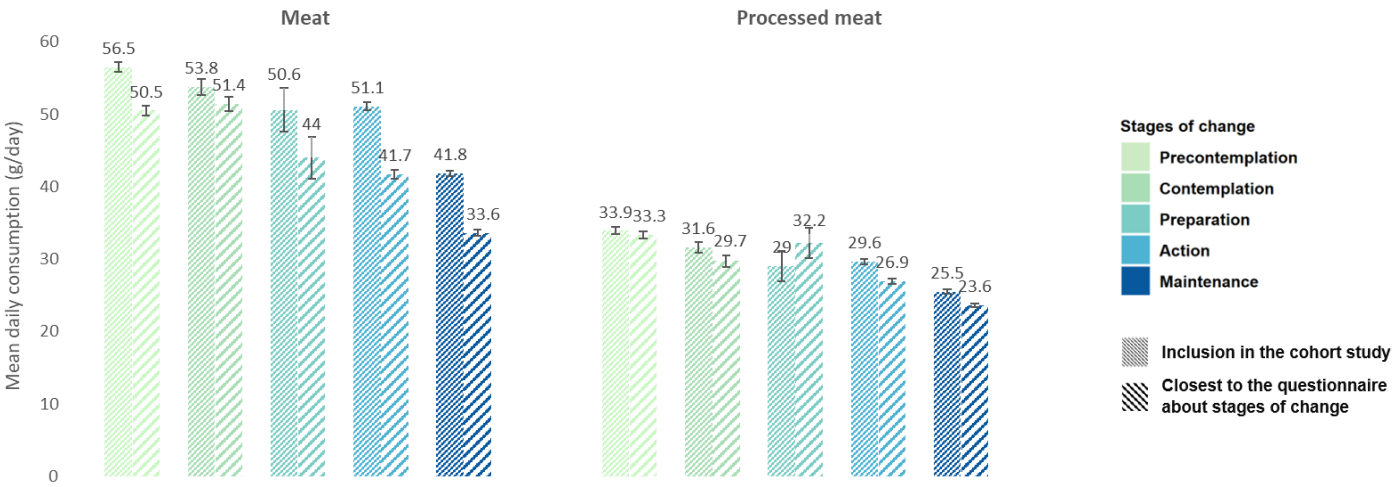
| | **Total sample (n = 25,143)** | |
|---|---|---|
| | ***n*** | **% or mean (SD)** |
| **Sex** | | |
| Men | 6326 | 25.2 |
| Women | 18817 | 74.8 |
| **Age (y)** | | 56.4 (13.8) |
| **Age (y, category)** | | |
| [18-30[ | 683 | 2.7 |
| [30-50[ | 7127 | 28.4 |
| [50-65[ | 8743 | 34.8 |
| [65+[ | 8590 | 34.2 |
| **Monthly household income class (per u.c.)** | | |
| < 1200 € | 3293 | 13.1 |
| 1200–1800 € | 5044 | 20.1 |
| 1800–2700 € | 5966 | 23.7 |
| > 2700 € | 8478 | 33.7 |
| Refused to declare | 2362 | 9.4 |
| **Occupational category** | | |
| Self-employed, farmer, employee, manual worker | 6510 | 25.9 |
| Intermediate profession | 6254 | 24.9 |
| Managerial staff, intellectual profession | 10388 | 41.3 |
| Unemployed | 1830 | 7.3 |
| No occupation | 161 | 0.6 |
| **Educational level** | | |
| None or primary | 428 | 1.7 |
| Secondary | 6696 | 26.6 |
| Undergraduate and others | 8044 | 32.0 |
| Postgraduate | 9975 | 39.7 |
| **Household composition** | | |
| Alone without children | 4612 | 18.3 |
| Alone with at least one child | 1621 | 6.5 |
| Two adults living as a couple without children | 10800 | 43.0 |
| Two adults living as a couple with at least one child | 7714 | 30.7 |
| Two or more adult without children | 396 | 1.6 |
| **Size of urban residence unit** | | |
| Rural | 5602 | 22.3 |
| < 20,000 inhabitants | 3877 | 15.4 |
| 20,000–200,000 inhabitants | 4707 | 18.7 |
| > 200,000 inhabitants | 10957 | 43.6 |
| **Last weight-loss diet followed** | | |
| Not declaring a weight-loss diet | 9615 | 38.2 |
| < 5 years | 1700 | 6.8 |
| > 5 years | 13828 | 55.0 |
| **BMI** | | |
| Underweight | 1040 | 4.1 |
| Normal | 15426 | 61.4 |
| Overweight | 6229 | 24.8 |
| Obesity | 2448 | 9.7 |
| **Physical activity** | | |
| Low physical activity | 4311 | 17.2 |

| | | |
|---|---|---|
| Moderate physical activity | 9840 | 39.1 |
| High physical activity | 10992 | 43.7 |
| | | |
| **Stages of change** | | |
| Precontemplation | 3141 | 12.5 |
| Contemplation[1] | 1454 | 5.8 |
| *Participants who declared meat reduction (%)* | *916* | *63.0* |
| *Participants who declared meat continuation (%)* | *538* | *37.0* |
| Preparation | 184 | 0.7 |
| Action | 5052 | 20.1 |
| Maintenance | 10509 | 41.8 |

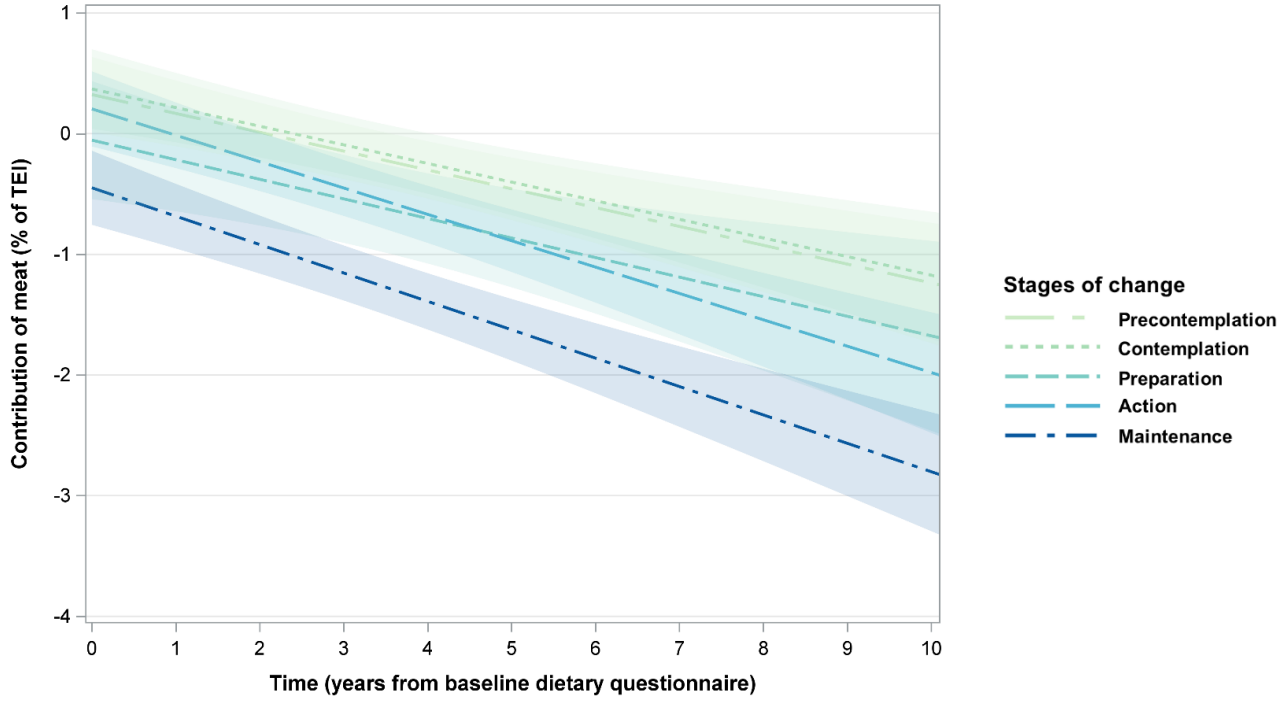
[1] Participants identified in the contemplation stage could either respond that they were thinking of reducing their meat consumption or that they were continuing their meat consumption.

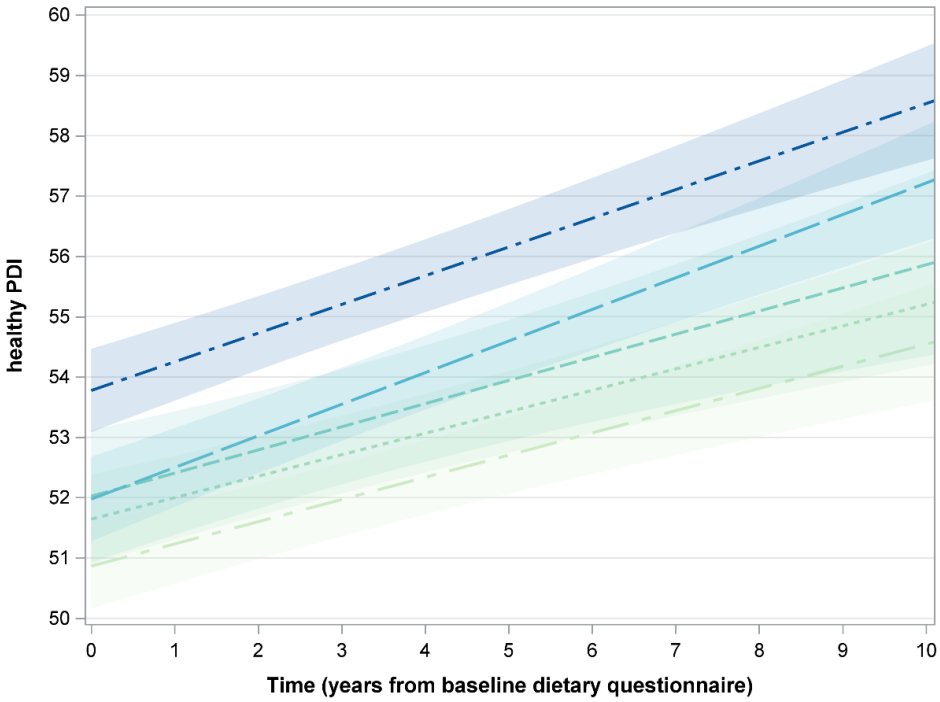
Figure 1. Adjusted mean daily consumption of meat and processed meat (and SEM) at the inclusion in the cohort and closest to the questionnaire on stages of change, according to stage of changes ($n$ = 25,143) (A) [1] and changes in percent energy intake provided by meat (logarithm of the contribution of the given food to total energy intake, $n$ = 24,715) and in healthy PDI ($n$ = 25,143) over time according to the group of individuals in stages of change in French adults participating in the NutriNet-Santé cohort (multivariate linear mixed models)[2] (B).

**(A)**




**(B)**






[1] Mean daily consumptions have been adjusted for sex, age (continuous) and mean total energy intake
[2] The mean predicted trajectories (solid lines) with 95% confidence intervals (indicated with shading) were plotted for a chosen profile of covariates. We chose the mean number of dietary records (7.8), of an average study participant profile at the date of the questionnaire on stages of change: a woman, aged 56.4 years, with a total energy intake equal to 1832 kcal (for hPDI only), with an educational level higher than primary, with an occupational category not corresponding to self-employed, farmer, employee or manual worker, with a monthly household income higher than 1200 €, not living in alone, living in a city, with a BMI corresponding to WHO categories of "underweight", "overweight" or "obesity", declaring a weight-loss diet and with a moderate or high physical activity. Note that the choice of profile was made to optimize graphical representation and has no influence on the differences in trajectories estimated by the model.
Data not shown for the group "Other".

Table 2. Comparison of adjusted frequencies according to different types of motives related to meat reduction and stages of change towards meat reduction, NutriNet-Santé, n=16,661 [1]

| | Contemplation (*n* = 916) | Preparation (*n* = 184) | Action (*n* = 5052) | Maintenance (*n* = 10,509) |
|---|---|---|---|---|
| | % [2] | % [2] | % [2] | % [2] |
| **I don't like the taste of meat** | | | | |
| No motive | 98.1 | 98.4 | 97 | 94 |
| Motive, not change-inducing | 0.4 | 0 | 0.3 | 0.5 |
| Change-inducing motive | 1.5 | 1.6 | 2.7 | 5.5 |
| **I don't like the sight or the handling of meat, especially raw meat** | | | | |
| No motive | 86.6 | 91.9 | 88.1 | 84.6 |
| Motive, not change-inducing | 7.5 | 4.3 | 5.3 | 6.2 |
| Change-inducing motive | 5.8 | 3.8 | 6.6 | 9.2 |
| **I think it's good to vary my diet and my protein sources by eating something different than meat** | | | | |
| No motive | 17.7 | 14 | 11.8 | 9.9 |
| Motive, not change-inducing | 33.9 | 19.9 | 16.7 | 18.4 |
| Change-inducing motive | 48.4 | 66 | 71.4 | 71.7 |
| **I think it's healthier not to eat too much meat** | | | | |
| No motive | 23.5 | 21.3 | 15.2 | 12.7 |
| Motive, not change-inducing | 25.5 | 17.7 | 10.5 | 11.9 |
| Change-inducing motive | 51 | 61 | 74.3 | 75.3 |
| **I think it's healthier to avoid meat** | | | | |
| No motive | 94.7 | 97.3 | 93.1 | 90.3 |
| Motive, not change-inducing | 2 | 0.9 | 0.5 | 1.4 |
| Change-inducing motive | 3.3 | 1.8 | 6.3 | 8.3 |
| **I care about animal welfare or the lives of animals** | | | | |
| No motive | 34.3 | 34 | 34.7 | 29.3 |
| Motive, not change-inducing | 32.6 | 30 | 22.5 | 23.2 |
| Change-inducing motive | 33.1 | 36 | 42.8 | 47.4 |

| | | | | |
|---|---|---|---|---|
| **I think it's better for the environment not to eat too much meat** | | | | |
| No motive | 25 | 22.9 | 21.5 | 17.9 |
| Motive, not change-inducing | 29.6 | 21.6 | 15.7 | 15.6 |
| Change-inducing motive | 45.4 | 55.5 | 62.8 | 66.5 |
| **The people I live with don't like or eat meat** | | | | |
| No motive | 95.5 | 95.5 | 90.7 | 87.9 |
| Motive, not change-inducing | 1.9 | 0.7 | 1.9 | 3.4 |
| Change-inducing motive | 2.6 | 3.8 | 7.4 | 8.8 |
| **My doctor advises me to reduce my meat consumption** | | | | |
| No motive | 96.2 | 96.9 | 94.4 | 94.8 |
| Motive, not change-inducing | 0 | 0 | 0 | 0 |
| Change-inducing motive | 3.8 | 3.1 | 5.6 | 5.2 |
| **I am cutting back on my budget by eating less meat** | | | | |
| No motive | 57.4 | 49.3 | 46.6 | 45.3 |
| Motive, not change-inducing | 21.3 | 22.2 | 18.3 | 18.6 |
| Change-inducing motive | 21.3 | 28.6 | 35.1 | 36.1 |
| **I have trouble finding meat that I consider to be of good quality** | | | | |
| No motive | 67.5 | 69.2 | 65.3 | 63.7 |
| Motive, not change-inducing | 15.5 | 12.7 | 9.4 | 8.3 |
| Change-inducing motive | 17 | 18.1 | 25.3 | 28 |
| **I have difficulty preserving the meat I buy** | | | | |
| No motive | 91.2 | 93.8 | 93.5 | 93.8 |
| Motive, not change-inducing | 3.6 | 2.9 | 2 | 1.7 |
| Change-inducing motive | 5.2 | 3.3 | 4.6 | 4.5 |

[1] This subsample includes participants who declared a meat reduction in contemplation, preparation, action and maintenance stages, which explains the variations in the total number of participants (data for the "Other" group not shown)

[2] Percentage adjusted for sex, age (continuous), educational level, monthly household income classes, occupational category, household composition, size of urban residence unit, BMI categories, last weight-loss diet and level of physical activity.

Table 3. Comparison of adjusted frequencies according to different types of motives hindering meat reduction and stages of change toward meat reduction, NutriNet-Santé (*n* = 3659) [1]

| | **Precontemplation (*n* = 3,141)** | **Contemplation (*n* = 518)** |
|---|---|---|
| | **%[2]** | **%[2]** |
| **I enjoy eating meat** | | |
| No motive | 12.3 | 20.3 |
| Motive, not change-hindering | 13.8 | 12.5 |
| Change-hindering motive | 73.9 | 67.1 |
| **I have trouble changing my meat-eating habits** | | |
| No motive | 55.4 | 39.3 |
| Motive, not change-hindering | 8.3 | 9.2 |
| Change-hindering motive | 36.3 | 51.5 |
| **I think meat is good for my health** | | |
| No motive | 22.1 | 43.6 |
| Motive, not change-hindering | 14.4 | 12.5 |
| Change-hindering motive | 63.6 | 43.9 |
| **I want to support farmers and meat producers** | | |
| No motive | 39.8 | 51.8 |
| Motive, not change-hindering | 23.6 | 19.8 |
| Change-hindering motive | 36.6 | 28.3 |
| **I think eating meat allows me to reach satiety** | | |
| No motive | 36.4 | 44.1 |
| Motive, not change-hindering | 20.1 | 20.3 |
| Change-hindering motive | 43.5 | 35.6 |
| **The people I live with like meat and want to eat it** | | |
| No motive | 29.3 | 32.5 |
| Motive, not change-hindering | 29.6 | 22.9 |
| Change-hindering motive | 41.1 | 44.5 |

| | | |
|---|---|---|
| **I don't know what to eat as a substitute of meat** | | |
| No motive | 79.2 | 65.3 |
| Motive, not change-hindering | 4.1 | 4.1 |
| Change-hindering motive | 16.7 | 30.6 |
| | | |
| **Meat is part of my culture** | | |
| No motive | 21.4 | 22.6 |
| Motive, not change-hindering | 28.9 | 24.4 |
| Change-hindering motive | 49.7 | 53 |
| | | |
| **I feel pressure from those around me to eat meat** | | |
| No motive | 99.2 | 97.8 |
| Motive, not change-hindering | 0.7 | 1.9 |
| Change-hindering motive | 0.1 | 0.3 |
| | | |
| **I think meat is a good source of protein** | | |
| No motive | 10.7 | 17.7 |
| Motive, not change-hindering | 25.3 | 28.9 |
| Change-hindering motive | 64 | 53.4 |
| | | |
| **I think meat gives me strength** | | |
| No motive | 49 | 57.7 |
| Motive, not change-hindering | 9.3 | 8.2 |
| Change-hindering motive | 41.8 | 34.1 |

[1] This sample includes participants who declared meat continuation in precontemplation and contemplation stages, which explains the variations in the total number of participants (data for the "Other" group not shown).

[2] Percentage adjusted for sex, age (continuous), educational level, monthly household income classes, occupational category, household composition, size of the urban residence unit, BMI categories, last weight-loss diet and level of physical activity.

**Stages of change toward meat reduction: Associations with motives and longitudinal dietary data on animal-based and plant-based food intakes in French adults. Reuzé al. 2023**

Supplemental Table 1: Items for meat reduction (for contemplation, preparation, action and maintenance stages) and meat continuation (for precontemplation and contemplation stages)

| Meat reduction | Meat continuation |
|---|---|
| I don't like the taste of meat | I enjoy eating meat |
| I don't like the sight or the handling of meat, especially raw meat | I have trouble changing my meat-eating habits |
| I think it's good to vary my diet and my protein sources by eating something different than meat | I think meat is good for my health |
| I think it's healthier not to eat too much meat | I have the will to support the farmers and the meat producers |
| I think it's healthier to avoid meat | I think eating meat allows me to reach satiety |
| I care about animal welfare or the lives of animals | The people I live with like meat and want to eat some |
| I think it's better for the environment not to eat too much meat | I don't know what to eat as a substitute of meat |
| The people I live with don't like or eat meat | Meat is part of my culture |
| My doctor advises me to reduce my meat consumption | I feel pressure from those around me to eat meat |
| I am cutting back on my budget by eating less meat | I think meat is a good source of protein |
| I have trouble finding meat that I consider to be of good quality: origin, traceability, hygiene, labeled meat, organic meat, or other quality criteria | I think meat gives me strength |
| I have difficulty preserving the meat I buy | |

Supplemental Table 2: Food groups used to calculate PDI, healthy PDIs and unhealthy PDIs.

| | | | PDI | hPDI | uPDI |
|---|---|---|---|---|---|
| **Plant-based foods** | **Healthy** | Whole grains | Positive score (1 to 5 based on consumption quintiles) | Positive score (1 to 5 based on consumption quintiles) | Reverse score (5 to 1 based on consumption quintiles) |
| | | Fruits | | | |
| | | Vegetables | | | |
| | | Nuts | | | |
| | | Legumes | | | |
| | | Vegetable oil | | | |
| | | Tea and coffee | | | |
| | **Unhealthy** | Refined grains | | Reverse score (5 to 1 based on consumption quintiles) | Positive score (1 to 5 based on consumption quintiles) |
| | | Potatoes | | | |
| | | Sugar sweetened beverages[1] | | | |
| | | Sweets and desserts | | | |
| | | Miscellaneous plant-based foods[2] | | | |
| | | *Plant-based Range* | | *12 to 60* | |
| **Animal-based foods** | | Animal added fats | Reverse score (5 to 1 based on consumption quintiles) | Reverse score (5 to 1 based on consumption quintiles) | Reverse score (5 to 1 based on consumption quintiles) |
| | | Dairy foods | | | |
| | | Eggs | | | |
| | | Fish and seafood | | | |
| | | Meat | | | |
| | | Miscellaneous animal-based foods | | | |
| | | *Animal-based Range* | | *6 to 30* | |
| **Total Range** | | | **18 to 90** | | |

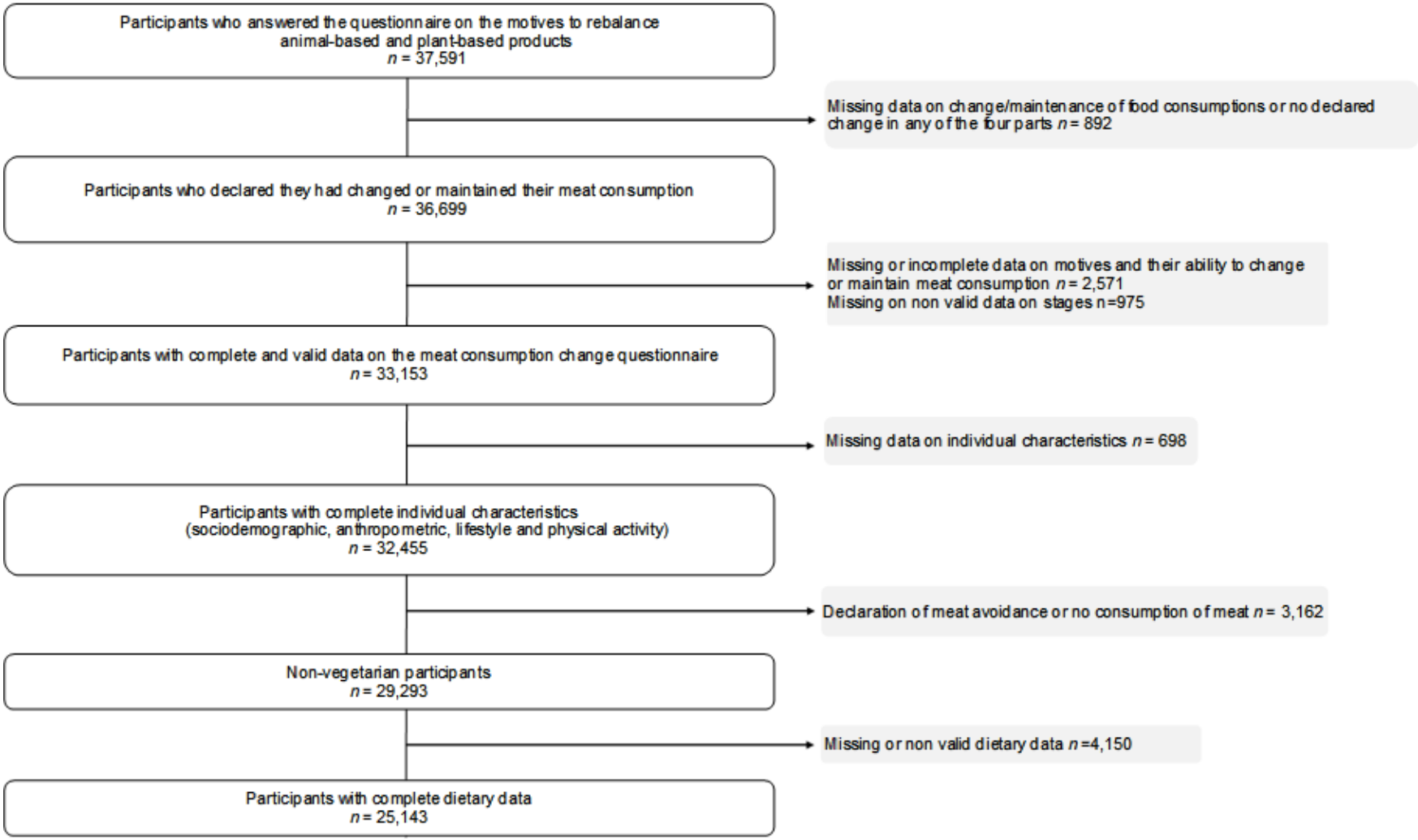
Abbreviations: PDI: Plant-based Diet Index

**List of modifications from the original study Satija et al.**

[1] Clustering of "Fruit juices" and "Sugar-sweetened beverages" groups

[2] Creation of the "Miscellaneous plant-based foods "group, including plant-based sugary or salty snacks, nuts and peanut butter, and plant-based meat and dairy substitutes. including all plant products used as substitutes for animal and all processed vegetarian products (protein substitutes, plant-based processed meats, dairy substitutes, plant-based salty snacks and fast food)

Supplemental Figure 1: Flowchart of the study.



Supplemental Table 3: Sociodemographic, anthropometric and lifestyle characteristics of participants according to stages of change, NutriNet-Santé, 2009-2018, n=25,143

| | Precontemplation (n=3,141) | | Contemplation (n=1,454) | | Preparation (n=184) | | Action (n=5,052) | | Maintenance (n=10,509) | | Others[1] (n=4,803) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | % | n | % | n | % | n | % | n | % | n | % | *P*[2] |
| **Sex** | | | | | | | | | | | | | < 0.0001 |
| Men | 1232 | 39.2 | 436 | 30.0 | 47 | 25.5 | 985 | 19.5 | 2657 | 25.3 | 969 | 20.2 | |
| Women | 1909 | 60.8 | 1018 | 70.0 | 137 | 74.5 | 4067 | 80.5 | 7852 | 74.7 | 3834 | 79.8 | |
| **Age (y)** | 57.6 (14.4) | | 54.1 (14.6) | | 55.0 (14.2) | | 54.3 (14.0) | | 57.2 (13.2) | | 56.7 (13.9) | | < 0.0001 |
| **Age (y, category)** | | | | | | | | | | | | | < 0.0001 |
| [18-30[ | 84 | 2.7 | 55 | 3.8 | 7 | 3.8 | 196 | 3.9 | 211 | 2.0 | 130 | 2.7 | |
| [30-50[ | 885 | 28.2 | 525 | 36.1 | 55 | 29.9 | 1642 | 32.5 | 2677 | 25.5 | 1343 | 28.0 | |
| [50-65[ | 908 | 28.9 | 425 | 29.2 | 69 | 37.5 | 1816 | 36.0 | 3920 | 37.3 | 1605 | 33.4 | |
| [65+[ | 1264 | 40.2 | 449 | 30.9 | 53 | 28.8 | 1398 | 27.7 | 3701 | 35.2 | 1725 | 35.9 | |
| **Monthly household income class (per c.u.)** | | | | | | | | | | | | | < 0.0001 |
| < 1200 € | 452 | 14.4 | 239 | 16.4 | 25 | 13.6 | 702 | 13.9 | 1172 | 11.2 | 703 | 14.6 | |
| 1200 - 1800 € | 706 | 22.5 | 346 | 23.8 | 46 | 25.0 | 1093 | 21.6 | 1876 | 17.9 | 977 | 20.3 | |
| 1800 - 2700 € | 763 | 24.3 | 354 | 24.4 | 40 | 21.7 | 1132 | 22.4 | 2546 | 24.2 | 1131 | 23.6 | |
| > 2700 € | 894 | 28.5 | 380 | 26.1 | 52 | 28.3 | 1648 | 32.6 | 4020 | 38.3 | 1484 | 30.9 | |
| Refused to declare | 326 | 10.4 | 135 | 9.3 | 21 | 11.4 | 477 | 9.4 | 895 | 8.5 | 508 | 10.6 | |
| **Occupational category** | | | | | | | | | | | | | < 0.0001 |
| Self-employed, farmer, employee, manual worker | 963 | 30.7 | 401 | 27.6 | 52 | 28.3 | 1346 | 26.6 | 2371 | 22.6 | 1377 | 28.7 | |
| Intermediate profession | 738 | 23.5 | 380 | 26.1 | 47 | 25.5 | 1246 | 24.7 | 2626 | 25.0 | 1217 | 25.3 | |
| Managerial staff. intellectual profession | 1215 | 38.7 | 571 | 39.3 | 60 | 32.6 | 2049 | 40.6 | 4683 | 44.6 | 1810 | 37.7 | |
| Unemployed | 203 | 6.5 | 91 | 6.3 | 20 | 10.9 | 376 | 7.4 | 776 | 7.4 | 364 | 7.6 | |
| No occupation | 22 | 0.7 | 11 | 0.8 | 5 | 2.7 | 35 | 0.7 | 53 | 0.5 | 35 | 0.7 | |
| **Educational level** | | | | | | | | | | | | | < 0.0001 |
| None or Primary | 85 | 2.7 | 27 | 1.9 | 3 | 1.6 | 88 | 1.7 | 135 | 1.3 | 90 | 1.9 | |
| Secondary | 1099 | 35.0 | 408 | 28.1 | 57 | 31.0 | 1264 | 25.0 | 2491 | 23.7 | 1377 | 28.7 | |
| Undergraduate and others | 927 | 29.5 | 487 | 33.5 | 51 | 27.7 | 1682 | 33.3 | 3377 | 32.1 | 1520 | 31.7 | |
| Post graduate | 1030 | 32.8 | 532 | 36.6 | 73 | 39.7 | 2018 | 39.9 | 4506 | 42.9 | 1816 | 37.8 | |
| **Household composition** | | | | | | | | | | | | | < 0.0001 |
| Alone without children | 569 | 18.1 | 185 | 12.7 | 18 | 9.8 | 863 | 17.1 | 1970 | 18.8 | 1007 | 21.0 | |
| Alone with at least one child | 194 | 6.2 | 80 | 5.5 | 10 | 5.4 | 335 | 6.6 | 690 | 6.6 | 312 | 6.5 | |
| Two adults living as a couple without children | 1394 | 44.4 | 619 | 42.6 | 82 | 44.6 | 2041 | 40.4 | 4605 | 43.8 | 2059 | 42.9 | |
| Two adults living as a couple with at least one child | 945 | 30.1 | 549 | 37.8 | 69 | 37.5 | 1732 | 34.3 | 3075 | 29.3 | 1344 | 28.0 | |
| Two or more adult without children | 39 | 1.2 | 21 | 1.4 | 5 | 2.7 | 81 | 1.6 | 169 | 1.6 | 81 | 1.7 | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Size of the urban residence unit** | | | | | | | | | | | | | < 0.0001 |
| Rural | 814 | 25.9 | 351 | 24.1 | 34 | 18.5 | 1168 | 23.1 | 2198 | 20.9 | 1037 | 21.6 | |
| < 20.000 inhabitants | 514 | 16.4 | 231 | 15.9 | 31 | 16.9 | 815 | 16.1 | 1576 | 15.0 | 710 | 14.8 | |
| 20.000 - 200.000 inhabitants | 591 | 18.8 | 278 | 19.1 | 38 | 20.7 | 900 | 17.8 | 1935 | 18.4 | 965 | 20.1 | |
| > 200.000 inhabitants | 1222 | 38.9 | 594 | 40.9 | 81 | 44.0 | 2169 | 42.9 | 4800 | 45.7 | 2091 | 43.5 | |
| **Last weight-loss diet followed** | | | | | | | | | | | | | < 0.0001 |
| Not declaring a weight-loss diet | 1213 | 38.6 | 505 | 34.7 | 58 | 31.5 | 1634 | 32.3 | 4133 | 39.3 | 2072 | 43.1 | |
| < 5 years | 189 | 6.0 | 106 | 7.3 | 9 | 4.9 | 370 | 7.3 | 741 | 7.1 | 285 | 5.9 | |
| > 5 years | 1739 | 55.4 | 843 | 58.0 | 117 | 63.6 | 3048 | 60.3 | 5635 | 53.6 | 2446 | 50.9 | |
| **BMI** | | | | | | | | | | | | | < 0.0001 |
| Underweight | 95 | 3.0 | 43 | 3.0 | 6 | 3.3 | 179 | 3.5 | 448 | 4.3 | 269 | 5.6 | |
| Normal | 1577 | 50.2 | 821 | 56.5 | 94 | 51.1 | 3017 | 59.7 | 6800 | 64.7 | 3117 | 64.9 | |
| Overweight | 1003 | 31.9 | 413 | 28.4 | 50 | 27.2 | 1315 | 26.0 | 2421 | 23.0 | 1027 | 21.4 | |
| Obesity | 466 | 14.8 | 177 | 12.2 | 34 | 18.5 | 541 | 10.7 | 840 | 8.0 | 390 | 8.1 | |
| **Physical activity** | | | | | | | | | | | | | < 0.0001 |
| Low physical activity | 625 | 19.9 | 337 | 23.2 | 44 | 23.9 | 938 | 18.6 | 1610 | 15.3 | 757 | 15.8 | |
| Moderate physical activity | 1129 | 35.9 | 596 | 41.0 | 67 | 36.4 | 2121 | 42.0 | 4093 | 39.0 | 1834 | 38.2 | |
| High physical activity | 1387 | 44.2 | 521 | 35.8 | 73 | 39.7 | 1993 | 39.5 | 4806 | 45.7 | 2212 | 46.1 | |

[1] Other: participants who answered “No, it's for another reason” and “No, because I was already eating little meat.” to the question “*In recent years, have you reduced your meat consumption*?”.
[2] Chi2 tests or ANOVA

Supplemental Table 4: Percentage of consumers and adjusted mean daily consumption and dietary indices (mean and SEM), among consumers, at the inclusion in the cohort and at the latest available follow-up, according to stages of changes, NutriNet-Santé, n=25,143[1]

| | Precontemplation (n=3,141) | | | | | | Contemplation (n=1,454) | | | | | | Preparation (n=184) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inclusion | | | Latest available follow-up | | | Inclusion | | | Latest available follow-up | | | Inclusion | | | Latest available follow-up | | |
| | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM |
| **Plant-based foods** | | | | | | | | | | | | | | | | | | |
| Fruits (g/d) | 89.9 | 200.3 | 2.8 | 89.0 | 191.9 | 2.8 | 92.2 | 203.1 | 4 | 89.8 | 193.2 | 4 | 93.5 | 203.3 | 11.1 | 92.9 | 198.5 | 11.1 |
| Vegetables (g/d) | 99.2 | 229.3 | 2.7 | 98.6 | 222.4 | 2.7 | 99.0 | 237.3 | 3.9 | 98.7 | 234.3 | 4 | 99.5 | 259.3 | 10.9 | 100.0 | 261 | 11 |
| Legumes (g/d) | 26.5 | 37.2 | 1.2 | 23.2 | 39.3 | 1.4 | 27.8 | 40.7 | 1.8 | 24.5 | 39.3 | 2 | 27.2 | 33.8 | 5.1 | 27.2 | 38.7 | 5.2 |
| Potatoes and other tubers (g/d) | 68.2 | 66 | 1.1 | 66.0 | 66.9 | 1.1 | 70.9 | 67.2 | 1.5 | 67.5 | 68.2 | 1.5 | 66.3 | 60.1 | 4.4 | 65.2 | 66.2 | 4.4 |
| Whole grains (g/d) | 48.7 | 52.1 | 1.3 | 48.2 | 57.5 | 1.3 | 57.3 | 54.2 | 1.8 | 55.8 | 55.2 | 1.8 | 63.0 | 60.2 | 4.6 | 56.0 | 59.4 | 4.9 |
| Refined cereals and grains (g/d) | 98.2 | 155 | 1.5 | 96.8 | 137 | 1.4 | 98.4 | 160.4 | 2.1 | 97.2 | 140.5 | 2 | 98.9 | 156.9 | 5.9 | 97.3 | 137.9 | 5.7 |
| Sweet and desserts (g/d) | 97.3 | 98.9 | 1.2 | 95.3 | 95.9 | 1.2 | 97.9 | 97.5 | 1.7 | 96.5 | 96.7 | 1.7 | 97.3 | 105.5 | 4.8 | 96.7 | 96.5 | 4.8 |
| Nuts (g/d) | 21.7 | 10.9 | 0.6 | 25.0 | 9.3 | 0.6 | 23.0 | 11.5 | 0.9 | 28.5 | 9.9 | 0.8 | 28.8 | 9.9 | 2.3 | 31.5 | 9 | 2 |
| Vegetable oil (g/d) | 75.2 | 9.4 | 0.2 | 72.2 | 8.4 | 0.2 | 79.8 | 9.7 | 0.3 | 73.8 | 8.5 | 0.3 | 81.5 | 9.8 | 0.7 | 72.3 | 7.9 | 0.7 |
| Uncooked cereals and seeds (g/d) | 2.1 | 12.9 | 1.6 | 2.3 | 15.7 | 1.6 | 2.1 | 11.1 | 2.3 | 3.7 | 10.2 | 1.9 | 3.8 | 9.6 | 4.8 | 7.1 | 15 | 3.8 |
| Miscellaneous (g/d) | 22.8 | 14.3 | 0.6 | 20.2 | 16.4 | 0.9 | 22.6 | 13.1 | 0.9 | 21.1 | 12.1 | 1.2 | 19.6 | 12.6 | 2.8 | 22.3 | 17 | 3.4 |
| Dairy substitutes (g/d) | 2.0 | 85.6 | 6.3 | 2.5 | 78.6 | 6.1 | 4.8 | 74.9 | 6 | 4.1 | 74.5 | 7.2 | 6.0 | 58.5 | 15.1 | 4.3 | 63.2 | 19.1 |
| Meat substitutes (g/d) | 0.4 | 38.3 | 5.8 | 0.5 | 43.3 | 6.9 | 0.6 | 39.9 | 6.4 | 1.6 | 48.1 | 6 | 0.5 | 30.6 | 19.3 | 1.1 | 30.7 | 20 |
| Fermented and coagulated foods (g/d) | 0.3 | 27.5 | 7.1 | 0.1 | 37.6 | 12.6 | 0.5 | 38.5 | 8.1 | 0.4 | 41.5 | 10.3 | 0.5 | 1 | 21.3 | 1.1 | 26.8 | 18 |
| **Animal-based foods** | | | | | | | | | | | | | | | | | | |
| Meats (all types) (g/d) | 98.9 | 123.2 | 1 | 98.4 | 117 | 1 | 98.6 | 119.3 | 1.5 | 98.8 | 111.1 | 1.4 | 98.9 | 113.1 | 4.1 | 99.5 | 107.4 | 4 |
| Meat products[2] (g/d) | 96.5 | 98.9 | 0.9 | 95.8 | 92 | 0.9 | 96.1 | 93.8 | 1.3 | 95.1 | 88.2 | 1.3 | 95.7 | 88.1 | 3.7 | 96.2 | 82.6 | 3.6 |
| Meat (g/d) | 80.5 | 66.9 | 0.7 | 75.8 | 62.6 | 0.7 | 80.2 | 63.2 | 1.1 | 75.0 | 63.2 | 1.1 | 78.3 | 62 | 3.1 | 70.1 | 58.9 | 3.2 |
| Offal (g/d) | 13.0 | 41.8 | 1.2 | 79.9 | 42.8 | 1.3 | 12.9 | 41.2 | 1.7 | 10.5 | 39.3 | 2.1 | 12.0 | 40 | 5 | 12.5 | 35.8 | 5.3 |
| Processed meat (g/d) | 81.7 | 44.6 | 0.6 | 56.8 | 44.2 | 0.6 | 80.4 | 42.5 | 0.9 | 78.7 | 40.4 | 0.9 | 76.1 | 40.2 | 2.5 | 77.7 | 42.2 | 2.5 |
| Poultry (g/d) | 57.6 | 45.9 | 0.8 | 56.8 | 47.7 | 0.8 | 61.0 | 45.2 | 1.1 | 56.8 | 45 | 1.2 | 63.6 | 43.6 | 3 | 62.5 | 43.9 | 3.1 |
| Eggs (g/d) | 47.5 | 27.3 | 0.6 | 48.9 | 28.3 | 0.7 | 46.6 | 26.1 | 0.9 | 50.0 | 28 | 1 | 55.4 | 28.5 | 2.3 | 48.4 | 27.5 | 2.7 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dairy foods (g/d) | 98.6 | 249.8 | 2.9 | 97.9 | 227 | 2.6 | 98.7 | 234.9 | 4.2 | 97.6 | 206.2 | 3.9 | 98.4 | 252.9 | 11.7 | 97.8 | 212.1 | 10.7 |
| Animal added fats (g/d) | 67.5 | 10.4 | 0.2 | 63.3 | 11.8 | 0.2 | 72.1 | 10.5 | 0.3 | 67.4 | 12 | 0.3 | 67.9 | 9.9 | 0.7 | 61.4 | 11.4 | 0.8 |
| Fish and other seafood (g/d) | 73.1 | 58.3 | 0.9 | 68.0 | 54.4 | 0.9 | 74.8 | 58.6 | 1.4 | 67.2 | 57.8 | 1.4 | 79.9 | 54.8 | 3.7 | 77.2 | 53.3 | 3.6 |
| Miscellaneous (g/d) | 51.8 | 63 | 1.2 | 50.6 | 73 | 1.4 | 52.8 | 61.8 | 1.8 | 52.8 | 70.6 | 2.1 | 47.8 | 62.6 | 5.1 | 52.2 | 65.2 | 5.8 |
| **Beverages** | | | | | | | | | | | | | | | | | | |
| Sugar-sweetened drinks (mL/d) | 61.6 | 160.6 | 2.8 | 50.6 | 155.8 | 3 | 62.3 | 155.1 | 4.1 | 51.7 | 131.9 | 4.4 | 62.0 | 159.3 | 11.5 | 50.0 | 145 | 12.5 |
| Tea and coffee (mL/d) | 88.9 | 391.1 | 6.6 | 89.0 | 393 | 6.4 | 89.7 | 392.2 | 9.6 | 89.9 | 397 | 9.3 | 89.1 | 452.8 | 26.8 | 91.3 | 441.9 | 25.7 |
| Plant-based drinks (mL/d) | 2.3 | 137.3 | 12.7 | 3.0 | 155.1 | 11.3 | 3.4 | 129.4 | 15.4 | 5.0 | 128.4 | 12.8 | 7.1 | 81.6 | 30 | 8.2 | 91.1 | 27.7 |
| **Indices** | | | | | | | | | | | | | | | | | | |
| Contribution of meat products[2] (% of TEI) | 97.7 | 10.9 | 0.1 | 97.3 | 10.9 | 0.1 | 97.9 | 10.4 | 0.2 | 96.6 | 10.6 | 0.2 | 97.3 | 9.6 | 0.4 | 98.9 | 10 | 0.4 |
| Contribution of meat (% of TEI) | 85.2 | 6.6 | 0.1 | 82.2 | 6.5 | 0.1 | 86.3 | 6.2 | 0.1 | 81.6 | 6.8 | 0.1 | 82.1 | 6.1 | 0.3 | 79.3 | 5.8 | 0.4 |
| Contribution of processed meat (% of TEI) | 85.8 | 5.1 | 0.1 | 84.0 | 5.4 | 0.1 | 86.0 | 4.8 | 0.1 | 82.7 | 4.9 | 0.1 | 82.1 | 4.4 | 0.3 | 84.2 | 5.4 | 0.3 |
| PDI | 100.0 | 48.1 | 0.1 | 100.0 | 47.5 | 0.1 | 100.0 | 49 | 0.2 | 100.0 | 48.2 | 0.2 | 100.0 | 49.4 | 0.4 | 100.0 | 49 | 0.4 |
| healthyPDI | 100.0 | 52.7 | 0.1 | 100.0 | 53.7 | 0.1 | 100.0 | 53.6 | 0.2 | 100.0 | 54.5 | 0.2 | 100.0 | 54.2 | 0.5 | 100.0 | 55 | 0.5 |
| unhealthyPDI | 100.0 | 58.4 | 0.1 | 100.0 | 58.3 | 0.1 | 100.0 | 57.6 | 0.2 | 100.0 | 57.7 | 0.2 | 100.0 | 56.5 | 0.5 | 100.0 | 57.1 | 0.5 |

Abbreviations: TEI, total energy intake

[1] Mean daily consumption and mean PDIs, healthy PDIs and unhealthy PDIs have been adjusted for sex, age (continuous) and the mean total energy intake. Contribution of meat, processed meat and meat products to the total energy intake have been adjusted for sex and age.

[2] Including meat, offal and processed meat.

Supplemental Table 4 (continued): Percentage of consumers and adjusted mean daily consumption and dietary indices (mean and SEM), among consumers, at the inclusion in the cohort and at the latest available follow-up, according to stages of changes, NutriNet-Santé, n=25,143[1]

| | Action (n=5,052) | | | | | | Maintenance (n=10,509) | | | | | | Other (n=4,803) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inclusion | | | Latest available follow-up | | | Inclusion | | | Latest available follow-up | | | Inclusion | | | Latest available follow-up | | |
| | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM | % of consumers | Mean | SEM |
| **Plant-based foods** | | | | | | | | | | | | | | | | | | |
| Fruits (g/d) | 93.3 | 204.3 | 2.3 | 92.3 | 208.6 | 2.2 | 95.6 | 223 | 1.6 | 94.3 | 220.4 | 1.6 | 95.1 | 224.1 | 2.3 | 92.9 | 220.5 | 2.3 |
| Vegetables (g/d) | 99.6 | 248.5 | 2.2 | 99.4 | 254.2 | 2.2 | 99.7 | 268.8 | 1.6 | 99.6 | 268.1 | 1.6 | 99.6 | 263 | 2.2 | 99.6 | 257.1 | 2.3 |
| Legumes (g/d) | 28.1 | 37.2 | 1 | 26.8 | 41.9 | 1.1 | 28.6 | 40.5 | 0.7 | 28.8 | 45.3 | 0.7 | 27.9 | 42 | 1 | 25.9 | 44.4 | 1.1 |
| Potatoes and other tubers (g/d) | 66.4 | 64.1 | 0.9 | 62.5 | 63.2 | 0.9 | 64.1 | 65.2 | 0.6 | 60.1 | 64.6 | 0.6 | 64.1 | 65.6 | 0.9 | 59.8 | 63.2 | 0.9 |
| Whole grains (g/d) | 61.3 | 56.1 | 1 | 64.4 | 60.5 | 0.9 | 67.4 | 63 | 0.7 | 68.6 | 66.1 | 0.7 | 65.9 | 63 | 0.9 | 64.8 | 63.6 | 1 |
| Refined cereals and grains (g/d) | 98.0 | 155.8 | 1.2 | 96.7 | 137.2 | 1.1 | 97.7 | 154.9 | 0.9 | 95.8 | 134.8 | 0.8 | 97.6 | 154.9 | 1.2 | 95.7 | 137.7 | 1.2 |
| Sweet and desserts (g/d) | 98.0 | 103.4 | 1 | 96.5 | 96.6 | 1 | 97.9 | 104.4 | 0.7 | 96.9 | 96.9 | 0.7 | 98.0 | 106.9 | 1 | 96.9 | 101.1 | 1 |
| Nuts (g/d) | 26.5 | 11.1 | 0.5 | 35.9 | 11.5 | 0.4 | 33.1 | 13 | 0.3 | 44.2 | 13.1 | 0.3 | 31.6 | 13.1 | 0.5 | 39.6 | 12.9 | 0.4 |
| Vegetable oil (g/d) | 79.7 | 9.9 | 0.1 | 75.0 | 9.1 | 0.1 | 81.5 | 10.4 | 0.1 | 76.1 | 9.5 | 0.1 | 79.3 | 10.2 | 0.1 | 74.2 | 9.3 | 0.1 |
| Uncooked cereals and seeds (g/d) | 5.1 | 11.6 | 0.9 | 6.7 | 11.8 | 0.8 | 6.1 | 11.2 | 0.6 | 9.5 | 11.3 | 0.5 | 6.1 | 9.9 | 0.8 | 7.8 | 11.7 | 0.8 |
| Miscellaneous (g/d) | 23.1 | 13.8 | 0.5 | 21.6 | 17.4 | 0.7 | 21.3 | 14.1 | 0.4 | 21.7 | 17.2 | 0.5 | 19.8 | 13.6 | 0.6 | 20.0 | 17.5 | 0.7 |
| Dairy substitutes (g/d) | 5.1 | 70.1 | 3.3 | 6.0 | 77.9 | 3.4 | 7.6 | 75.2 | 2 | 8.1 | 79.8 | 2.2 | 6.7 | 76.4 | 3 | 7.3 | 81.1 | 3.1 |
| Meat substitutes (g/d) | 1.0 | 41.7 | 2.8 | 3.2 | 42.5 | 2.4 | 1.6 | 40.9 | 1.7 | 3.7 | 39.9 | 1.6 | 1.7 | 39.8 | 2.3 | 2.9 | 40.8 | 2.6 |
| Fermented and coagulated foods (g/d) | 0.6 | 33.4 | 4.1 | 1.0 | 31.8 | 4 | 1.4 | 32.9 | 2.2 | 1.6 | 36.1 | 2.5 | 1.2 | 31.8 | 3.1 | 1.1 | 29 | 3.7 |
| **Animal-based foods** | | | | | | | | | | | | | | | | | | |
| Meats (all types) (g/d) | 98.5 | 112.7 | 0.8 | 96.6 | 99.6 | 0.8 | 96.9 | 97.5 | 0.6 | 93.9 | 87.5 | 0.6 | 96.0 | 94.2 | 0.9 | 94.6 | 88.2 | 0.8 |
| Meat products[2] (g/d) | 95.8 | 88.4 | 0.7 | 91.4 | 78.3 | 0.7 | 92.3 | 76.6 | 0.5 | 87.6 | 68.4 | 0.5 | 90.8 | 73.8 | 0.8 | 88.5 | 68.9 | 0.8 |
| Meat (g/d) | 77.7 | 61.9 | 0.6 | 67.5 | 56.6 | 0.6 | 70.0 | 55.9 | 0.5 | 60.2 | 50.9 | 0.5 | 66.4 | 54.2 | 0.7 | 60.9 | 50.9 | 0.7 |
| Offal (g/d) | 11.6 | 41.5 | 1 | 10.3 | 41.3 | 1.1 | 10.5 | 41.3 | 0.7 | 10.2 | 40.5 | 0.8 | 10.4 | 40.9 | 1.1 | 9.9 | 41.2 | 1.2 |
| Processed meat (g/d) | 77.6 | 40.4 | 0.5 | 73.2 | 38.6 | 0.5 | 74.5 | 36.2 | 0.4 | 69.8 | 35.4 | 0.4 | 73.0 | 35.8 | 0.5 | 69.9 | 36 | 0.6 |
| Poultry (g/d) | 59.2 | 44.5 | 0.6 | 54.8 | 44.4 | 0.7 | 56.0 | 42.2 | 0.5 | 51.6 | 42.8 | 0.5 | 55.1 | 41.6 | 0.7 | 52.1 | 42.7 | 0.7 |
| Eggs (g/d) | 49.3 | 26.8 | 0.5 | 49.7 | 28.7 | 0.5 | 49.3 | 26.3 | 0.4 | 51.0 | 28.8 | 0.4 | 49.7 | 26.7 | 0.5 | 49.8 | 28.2 | 0.5 |

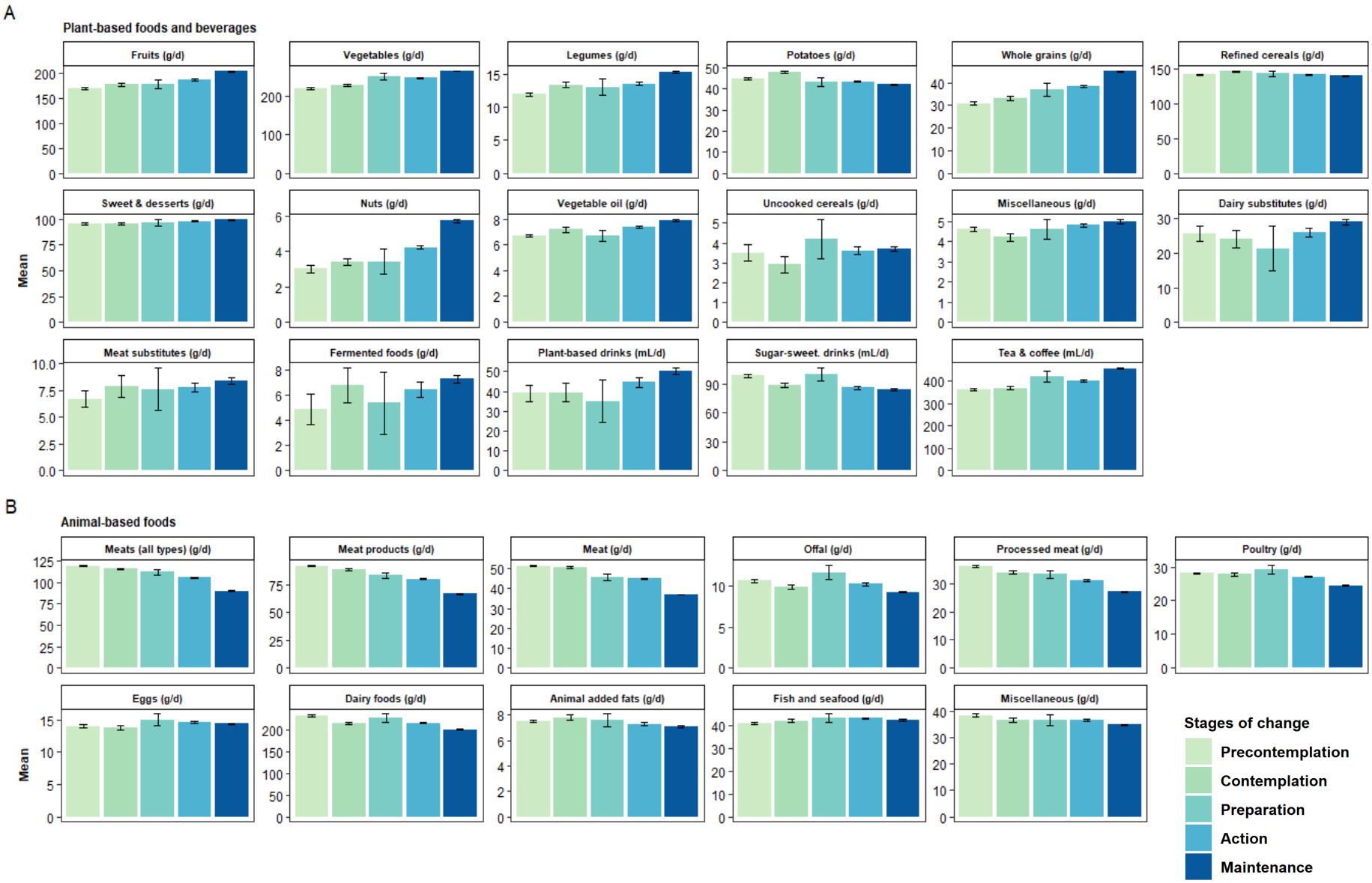
| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dairy foods (g/d) | 98.9 | 237.2 | 2.3 | 97.9 | 202.7 | 2.2 | 98.3 | 223.5 | 1.7 | 97.6 | 191.8 | 1.5 | 98.4 | 237.1 | 2.4 | 97.7 | 208.7 | 2.2 |
| Animal added fats (g/d) | 69.8 | 10.1 | 0.1 | 64.8 | 11.3 | 0.2 | 68.6 | 9.8 | 0.1 | 64.5 | 10.9 | 0.1 | 67.6 | 9.9 | 0.2 | 63.8 | 11.1 | 0.2 |
| Fish and other seafood (g/d) | 75.0 | 60.4 | 0.8 | 68.9 | 56.1 | 0.8 | 76.1 | 59 | 0.5 | 70.4 | 54.7 | 0.5 | 76.1 | 58.3 | 0.8 | 68.7 | 53.8 | 0.8 |
| Miscellaneous (g/d) | 53.0 | 61.6 | 1 | 51.2 | 70.1 | 1.2 | 49.4 | 60.1 | 0.7 | 47.5 | 69.4 | 0.9 | 49.3 | 61.3 | 1 | 47.3 | 69.8 | 1.3 |
| **Beverages** | | | | | | | | | | | | | | | | | | |
| Sugar-sweetened drinks (mL/d) | 62.2 | 146 | 2.3 | 49.9 | 132.1 | 2.5 | 60.7 | 143.8 | 1.7 | 49.6 | 128.8 | 1.8 | 60.1 | 145 | 2.4 | 48.6 | 134.8 | 2.6 |
| Tea and coffee (mL/d) | 90.9 | 425.2 | 5.4 | 91.9 | 433.2 | 5.2 | 93.1 | 478.4 | 3.8 | 93.5 | 481.1 | 3.7 | 91.7 | 467.7 | 5.4 | 92.9 | 471.5 | 5.2 |
| Plant-based drinks (mL/d) | 4.9 | 117.1 | 7.2 | 8.2 | 144.7 | 5.7 | 7.8 | 126.8 | 4.3 | 10.1 | 135 | 3.8 | 6.6 | 124.2 | 6.4 | 8.0 | 136.4 | 5.9 |
| **Indices** | | | | | | | | | | | | | | | | | | |
| Contribution of meat products[2] (% of TEI) | 97.1 | 9.9 | 0.1 | 94.4 | 9.3 | 0.1 | 94.6 | 8.5 | 0.1 | 90.7 | 8.2 | 0.1 | 93.2 | 8.3 | 0.1 | 91.6 | 8.3 | 0.1 |
| Contribution of meat (% of TEI) | 83.8 | 6 | 0.1 | 75.4 | 5.9 | 0.1 | 76.7 | 5.4 | 0 | 67.8 | 5.2 | 0.1 | 73.2 | 5.3 | 0.1 | 68.2 | 5.3 | 0.1 |
| Contribution of processed meat (% of TEI) | 83.0 | 4.6 | 0.1 | 79.1 | 4.7 | 0.1 | 79.5 | 4.1 | 0 | 74.9 | 4.4 | 0.1 | 77.6 | 4.1 | 0.1 | 74.7 | 4.4 | 0.1 |
| PDI | 100.0 | 49.5 | 0.1 | 100.0 | 49.7 | 0.1 | 100.0 | 51.2 | 0.1 | 100.0 | 51.2 | 0.1 | 100.0 | 50.8 | 0.1 | 100.0 | 50.5 | 0.1 |
| healthyPDI | 100.0 | 54.1 | 0.1 | 100.0 | 56.2 | 0.1 | 100.0 | 56 | 0.1 | 100.0 | 57.8 | 0.1 | 100.0 | 55.6 | 0.1 | 100.0 | 57 | 0.1 |
| unhealthyPDI | 100.0 | 57.2 | 0.1 | 100.0 | 56.8 | 0.1 | 100.0 | 56.7 | 0.1 | 100.0 | 56.3 | 0.1 | 100.0 | 57 | 0.1 | 100.0 | 56.9 | 0.1 |

Abbreviations: TEI, total energy intake

[1] Mean daily consumption and mean PDIs, healthy PDIs and unhealthy PDIs have been adjusted for sex, age (continuous) and the mean total energy intake. Contribution of meat, processed meat and meat products to the total energy intake have been adjusted for sex and age.

[2] Including meat, offal and processed meat.

Supplemental Figure 2: Adjusted mean daily consumption and contribution of plant-based and animal-based foods groups among consumers over the 2009-2019 period, n=25,143 [1]



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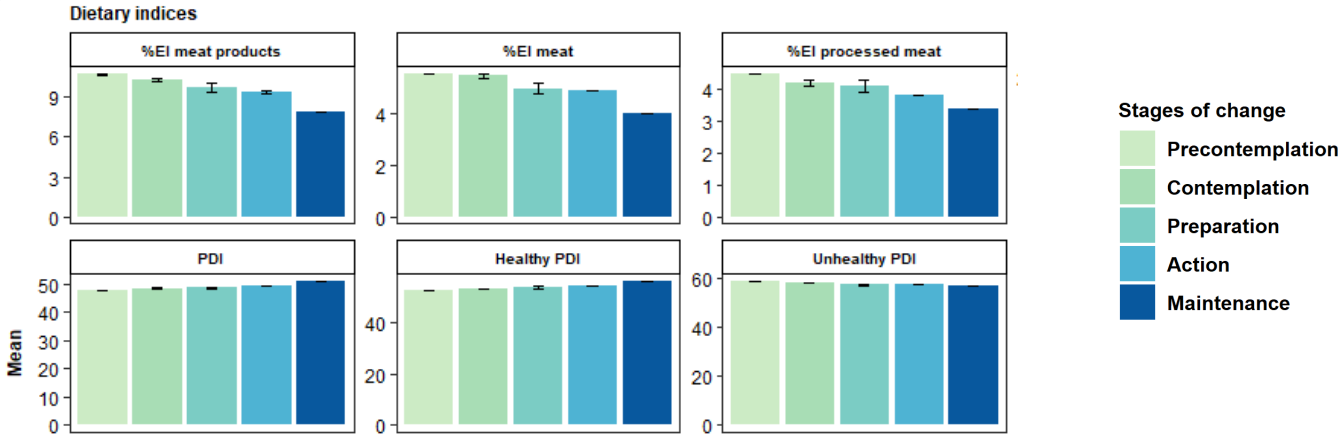


[1] Mean daily consumptions and indices have been calculated among consumers of the given food item. Mean daily consumption and mean PDIs, healthy PDIs and unhealthy PDIs have been adjusted for sex, age (continuous) and the mean total energy intake. Contribution of meat, processed meat and meat products to the total energy intake have been adjusted for sex and age.
Data not shown for the group "Other"
"Miscellaneous plant-based foods "group includes plant-based sugary or salty snacks, nuts and peanut butter, and plant-based meat and dairy substitutes. including all plant products used as substitutes for animal and all processed vegetarian products (protein substitutes, plant-based processed meats, dairy substitutes, plant-based salty snacks and fast food).
"Miscellaneous animal foods "group includes all dressings, sauces and animal-based salty snacks and fast foods.
"Fermented foods": Fermented or coagulated foods (e.g. tempeh, tofu...)
"Sugar-sweet. drinks": Sugar-sweetened drinks

Supplemental Table 5: Multivariate linear mixed analysis for the associations between stages of change towards meat reduction and changes in percent energy intake provided by meat, processed meat and meat products (logarithm of the contribution of the given food to total energy intake) over the 2009-2019 period in French adults participating in the NutriNet-Santé cohort (n = 25,143)[1]

| | **Contribution of meat to total energy intake (n=24,715) [2]** | | | **Contribution of processed meat to total energy intake (n=24,820) [2]** | | | **Contribution of meat products[3] to total energy intake (n=25,085) [2]** | | |
|---|---|---|---|---|---|---|---|---|---|
| | β | 95%IC | *p* | β | 95%IC | *p* | β | 95%IC | *p* |
| **Intercept** | 0.29 | [-0.07;0.65] | 0.12 | **1.43** | **[1.06;1.8]** | **<0.0001** | **2.13** | **[1.91;2.36]** | **<0.0001** |
| **Time** | **-0.23** | **[-0.31;-0.15]** | **<0.0001** | **-0.13** | **[-0.21;-0.05]** | **0.001** | **-0.09** | **[-0.14;-0.04]** | **0.001** |
| **Contemplation** | 0.05 | [-0.12;0.21] | 0.57 | -0.15 | [-0.31;0.02] | 0.08 | -0.04 | [-0.14;0.06] | 0.45 |
| **Contemplation*time** | 0.00 | [-0.03;0.04] | 0.92 | 0.00 | [-0.03;0.03] | 0.98 | 0.00 | [-0.02;0.03] | 0.76 |
| **Preparation** | -0.38 | [-0.77;0.02] | 0.06 | -0.25 | [-0.65;0.15] | 0.22 | -0.20 | [-0.44;0.05] | 0.11 |
| **Preparation*time** | -0.01 | [-0.09;0.08] | 0.89 | 0.04 | [-0.05;0.12] | 0.39 | 0.01 | [-0.04;0.07] | 0.58 |
| **Action** | **-0.12** | **[-0.24;0]** | **0.05** | **-0.21** | **[-0.33;-0.08]** | **0.001** | **-0.07** | **[-0.15;0]** | **0.05** |
| **Action*time** | **-0.06** | **[-0.09;-0.04]** | **<0.0001** | **-0.04** | **[-0.07;-0.02]** | **0.001** | **-0.04** | **[-0.06;-0.03]** | **<0.0001** |
| **Maintenance** | **-0.77** | **[-0.88;-0.67]** | **<0.0001** | **-0.53** | **[-0.64;-0.43]** | **<0.0001** | **-0.46** | **[-0.52;-0.39]** | **<0.0001** |
| **Maintenance*time** | **-0.08** | **[-0.1;-0.06]** | **<0.0001** | **-0.05** | **[-0.07;-0.02]** | **<0.0001** | **-0.06** | **[-0.07;-0.04]** | **<0.0001** |

[1] Multivariate linear mixed models were performed on the total sample, including participants in precontemplation, contemplation, preparation, action and maintenance stages and the group "Other". Non-consumers were excluded in each sample. Precontemplation stage was used as the category of reference. No significance over time for the group "Other", data not shown.

[2] Coefficients β were computed using a linear multilevel mixed model expressing the relationship between stages of change and dietary indices (expressed by the mean) and time (in years). Logarithm of the contribution of meat, processed meat and meat products to the total energy intake was used to increase normality and model's residual fitness. The coefficient for intercept represents the association of individuals in the precontemplation stage (reference) with baseline consumption and the coefficient for time represents the evolution of consumption over time for the precontemplation stage. The coefficient for stages of change represents the association of individuals in the stage of change with baseline consumption. The coefficient for the interaction term represents the association of individuals in stages of change with evolution of consumption over time, compared to the evolution of consumption of those in the precontemplation stage.

Models for sex, age (continuous), educational level, number of follow-up at which dietary data were recorded (continuous), monthly household income classes, occupational category, household composition, size of the urban residence unit, BMI category, latest weight-loss diet and physical activity level.

[3] Including meat, offal and processed meat.

Supplemental Table 6: Multivariate linear mixed analysis showing associations between stages of change towards meat reduction and changes in PDI, healthy PDI and unhealthy PDI over the 2009-2019 period in French adults participating in the NutriNet-Santé cohort (n = 25,143)[1]

| | PDI[2] | | | healthyPDI[2] | | | unhealthyPDI[2] | | |
|---|---|---|---|---|---|---|---|---|---|
| | **β** | **95%CI** | ***p*** | **β** | **95%CI** | ***p*** | **β** | **95%CI** | ***p*** |
| **Intercept** | **41.43** | **[40.67;42.2]** | **<0.0001** | **44.91** | **[44;45.82]** | **<0.0001** | **71.62** | **[70.79;72.44]** | **<0.0001** |
| **Time** | -0.04 | [-0.17;0.08] | 0.49 | **1.24** | **[1.09;1.38]** | **<0.0001** | -0.07 | [-0.21;0.07] | 0.35 |
| **Contemplation** | **0.93** | **[0.62;1.25]** | **<0.0001** | **0.78** | **[0.41;1.15]** | **<0.0001** | **-0.63** | **[-0.97;-0.3]** | **0.00** |
| **Contemplation*time** | -0.04 | [-0.09;0.01] | 0.16 | -0.01 | [-0.07;0.04] | 0.67 | 0.02 | [-0.04;0.07] | 0.55 |
| **Preparation** | **1.35** | **[0.6;2.09]** | **0.00** | **1.16** | **[0.28;2.04]** | **0.01** | **-1.26** | **[-2.06;-0.46]** | **0.00** |
| **Preparation*time** | 0.00 | [-0.12;0.12] | 0.96 | 0.02 | [-0.12;0.15] | 0.83 | 0.00 | [-0.14;0.13] | 0.98 |
| **Action** | **1.13** | **[0.91;1.36]** | **<0.0001** | **1.11** | **[0.84;1.38]** | **<0.0001** | **-0.94** | **[-1.18;-0.7]** | **<0.0001** |
| **Action*time** | **0.13** | **[0.09;0.16]** | **<0.0001** | **0.16** | **[0.11;0.2]** | **<0.0001** | -0.04 | [-0.08;0] | 0.05 |
| **Maintenance** | **2.63** | **[2.43;2.83]** | **<0.0001** | **2.91** | **[2.67;3.15]** | **<0.0001** | **-1.44** | **[-1.66;-1.22]** | **<0.0001** |
| **Maintenance*time** | **0.10** | **[0.07;0.13]** | **<0.0001** | **0.11** | **[0.07;0.14]** | **<0.0001** | -0.02 | [-0.06;0.01] | 0.25 |

[1] Multivariate linear mixed models were performed on the total sample, including participants in precontemplation, contemplation, preparation, action and maintenance stages and the group "Other". Precontemplation stage was used as the category of reference. No significance over time for the group "Other", data not shown.

[2] Coefficients β were computed using a linear multilevel mixed model expressing the relationship between stages of change and dietary indices (expressed the mean) and time (in days). The coefficient for intercept represents the association of individuals in the precontemplation stage (reference) with baseline consumption and the coefficient for time represents the evolution of consumption over time for the precontemplation stage. The coefficient for stages of change represents the association of individuals in stages of change with baseline consumption. The coefficient for the interaction term represents the association of individuals in stages of change with evolution of consumption over time, compared to the evolution of consumption those in the precontemplation stage.

Models were adjusted for sex, age (continuous), educational level, number of follow-up at which dietary data were recorded (continuous), monthly household income classes, occupational category, household composition, size of the urban residence unit, BMI category, latest weight-loss diet, physical activity level and total energy intake.