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OPEN Feasibility and potential effect of a pilot blended digital behavior change intervention promoting sustainable diets over a year

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Well-designed effective interventions promoting sustainable diets are urgently needed to benefit both human and planetary health. This study evaluated the feasibility, acceptability, and potential impact of a pilot blended digital intervention aimed at promoting sustainable diets. We conducted a series of ABA n-of-1 trials with baseline, intervention, and follow-up phases over the course of a year, involving twelve participants. The intervention included text messages, and individualized online feedback sessions. Quantitative data on diet composition was collected daily for 15 weeks distributed over the year. Qualitative data was collected through interviews at the end of each phase. Results showed high feasibility and acceptability: 100% retention rate, 75% attendance at all feedback sessions, and an average response rate of 86% to the dietary questionnaires. The intervention had a positive and significant effect on the overall diet composition. Specifically, 92% of the participants significantly increased their daily fruit and vegetable consumption, and 58% significantly reduced their intake of red and processed meat as well as ultra-processed foods. Participants also reported reducing food waste, choosing minimally packaged and in-season foods, and prioritizing fair-sourced food. The study demonstrates the potential of digital interventions to effectively promote sustainable dietary behaviors and offers insights for future large-scale implementations. Upcoming iterations should involve a more diverse population, particularly less motivated individuals and with more diverse socioeconomic status.

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Keywords Eating behavior change, Dietary sustainability, Nutritional education, eHealth, mHealth, N-of-1

Sustainable diets are defined by three key dimensions: promoting human health, minimizing environmental impact, and supporting socio-economic well-being¹. In Spain—where the current intervention was implemented—as in other high-income countries^{2,3}, general dietary patterns are significantly unsustainable. On the health dimension, diet-related diseases, such as cardiovascular diseases, obesity, or type 2 diabetes, are responsible for 80,000 deaths yearly in Spain⁴. In parallel, food consumption is the primary behavior among Spaniards contributing to environmental degradation and resource overuse⁵. Further, on the socio-economic perspective, it is known that part of the food consumed within the country is not sourced ethically⁶. To address this situation, changing current eating behaviors toward whole plant-based diets, in combination with a reduction in food waste, may yield benefits for human health and the planet, and promote a health-promoting

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food system that operates within planetary boundaries^{4,7,8}. Moreover, purchasing food from fair and equitable sources can help to promote a more just and sustainable food system^{9–11}.

A significant part of the population in high-income countries seems to be willing to follow sustainable diets (e.g. see^{12,13} for Spain, and¹⁴ for a more global perspective). Nevertheless, they have acknowledged not knowing how to implement the required behavior changes in practice. So far, however, existing efforts to promote sustainable diets have focused primarily on encouraging adherence to a healthy diet with low environmental impact, but have overlooked other critical factors such as food waste^{15,16} and food's socio-economic consequences¹⁶. It is important to note that the dimensions of dietary sustainability are not always aligned. For instance, a healthy food like fish can have a high environmental impact depending on the targeted fish stock and the fishing techniques employed^{17,18}. Additionally, labor conditions for fisheries workers may not be fair, compromising their well-being¹⁹. Trade-offs can even occur within the same dimension; for instance, the environmental benefits of adopting a low-impact diet may be counteracted by increased food waste²⁰. This highlights the need for developing behavioral interventions that promote sustainable diets across all dimensions (i.e., human health, environmental, and socio-economic), and targeting diverse behaviors simultaneously.

To build on this, we developed a pilot blended digital intervention aimed at promoting behavior change toward sustainable diets in a holistic manner. The main objective of this study was to accumulate knowledge, experience, and pilot data to scale up an effective intervention for promoting sustainable diets. Thus, the study had two specific objectives: (i) to assess the feasibility and acceptability of the study design and related procedures (i.e., measurements and intervention features); and (ii) to evaluate the potential effects of such an intervention on dietary changes, considering not only diet composition but also other key behaviors related to sustainable diets.

Methods

This study follows a pre-registered protocol²¹. Deviations from the original protocol are discussed in Additional File 1.

Study population

Participants were approached by e-mailing employees of the Barcelona Institute for Global Health, through social media, with posters placed in public libraries, as well as word-of-mouth. The potential participants were invited to visit a website comprising a brief study description and a link to an online eligibility survey. This survey included specific questions designed to identify individuals meeting the inclusion criteria (refer to Additional File 2 for the complete list of items included in the eligibility survey).

Individuals were enrolled in the study if they met the following characteristics: adults aged 18 to 65 years; residing in the province of Barcelona; speaking and reading Spanish fluently; having a mobile phone supporting the installation of a smartphone app; and following an omnivorous diet. The exclusion criteria were being pregnant or planning to become pregnant in the next year; having given birth in the past 3 months; breastfeeding; being a professional athlete; following specific diets (e.g., slimming, gluten-free, low in sugars); reporting a history of eating disorders, any food intolerance or allergy, or other chronic illnesses that might directly impact eating behaviors; not taking their own decisions about food choices (e.g., someone else selects what they eat for most of their meals); and presenting eating behaviors already aligned with the principles of sustainable diets (i.e., scoring half or more of the points on the scale used in this study for measuring sustainable diets; see the next sections for a presentation of the scale and scoring procedure).

Study design

We implemented a series of N-of-1 pilot trials over the course of one year digitally. The trials had an ABA design, with the first A phase corresponding to a 2-week baseline evaluation, the B phase to a 22-week intervention, and the second A phase to a 24-week post-intervention follow-up (refer to Fig. 1 for an illustration of the three phases of the study). Interventions involved (i) app-based text messages and (ii) individualized online feedback sessions. Quantitative data were collected daily for 15 weeks over the course of the year with the app, and qualitative data were collected through three semi-structured online interviews to gain further insight into the study objectives. Prior to the study, individual online meetings with each participant were organized to assist them in installing the app on their mobile phones and to clarify any questions they might have about the app, assessment tools used, and procedures of the project.

Participants received financial incentives for their participation. For each of the 15 evaluation weeks, they received 10 euros if they fully completed at least 6 out of the 7-daily eating behavior questionnaires. Thus, in total, each participant could receive up to 150 euros over the year.

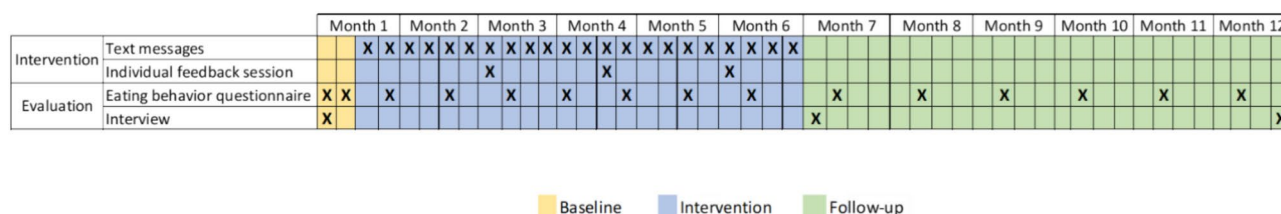


Fig. 1. Study timeline. Note: X represents the weeks during which that feature was implemented.

Intervention

The present intervention involved two components: generic text messages and individualized online feedback sessions.

Generic text messages were sent twice a week (Tuesdays and Fridays) during the interventional B phase, by means of the General Data Protection Regulation-compliant app *m-Path* (available at <https://m-path.io/landing/>). A total of 44 different messages were designed, each falling into one or more of the following categories: (i) educational messages on the health (e.g., debunking nutritional myths), environmental (e.g., pointing out the need of reducing the consumption of animal products, food waste or unnecessary food packaging), and socio-economic (e.g., highlighting the necessity of supporting small stakeholders within the food system) consequences of eating behaviors (n=18 messages out of 44); (ii) motivational messages to encourage sustainable diets, with tips on goal achievement (n=26 messages); and (iii) recipes for simple yet tasty sustainable meals (n=4 messages). These text messages were developed based on a previous scoping review to identify relevant behavior change techniques (BCTs) for changing eating behaviors²² and the compendium of self-enactable techniques v1.0²³. Their understandability was pre-tested on six individuals who met our inclusion criteria but were not involved in the project. The messages were refined based on their feedbacks, if necessary. All study participants were exposed to the entire repertoire of messages in a predetermined sequence. For detailed information on the final message content, order, and the specific BCTs employed, please refer to Additional File 3.

In addition to the text messages, three individualized, 15-min, online feedback sessions were offered every two evaluation weeks during the intervention phase (see Fig. 1). During these online feedback sessions, a member of the research team with extensive knowledge of sustainable diets (UF) commented with the participants on the food consumption as registered during the last two evaluation weeks. The researcher provided tailored advice on improving the healthiness and sustainability of their diets and addressed any questions or concerns participants might have had regarding sustainable diets. BCTs implemented in these sessions involved *feedbacks on behavior* (i.e., based on previous measurements), *instructions on how to perform the behavior* (e.g., cooking tips, substituting one type of food by another) and *information about the health, social and environmental consequences of food*. No goals were set as part of these sessions.

Measures

Socio-demographic characteristics of the participants

Participants completed an online baseline questionnaire that gathered information on various characteristics (see Additional File 4). For the purposes of this study, the relevant data included gender, age, highest level of education, and household income.

Quantitative indicators of feasibility and acceptability

Feasibility and acceptability were assessed using standard metrics commonly applied in pilot and feasibility studies within the digital behavior change domain, selected based on prior comparable research^{24,25}. Feasibility was quantitatively evaluated by assessing the capacity to recruit potential participants according to our inclusion/exclusion criteria, and the retention rate of enrolled participants. Acceptability of the intervention procedures was based on indicators of participant engagement, including the number of interventional text messages read (confirmed when scoring each message; see below), the number of food consumption questionnaires answered, and the number and total duration of individual feedback sessions attended. Additionally, the acceptability of the messages was assessed based on how useful, informative, or motivating participants found the information provided in each text message (all three characteristics were targeted in the same question). To measure this, we employed a single item with a visual Likert scale ranging from 0 to 100 points, with 0 representing the lowest score (i.e., no useful, informative or motivating) and 100 representing the highest (i.e., highly useful, informative or motivating). Participants filled out this scale for each text message they received.

Quantitative indicators of dietary change

In terms of sampling frequency, diet composition was assessed daily in the evening over a 15-week period throughout the year. Evaluation weeks included the 2 weeks of the baseline phase, every 3 weeks during the intervention (that lasted 22 weeks, so around seven assessment points during this period), and once a month during the follow-up period (Fig. 1). If necessary, this schedule was slightly modified due to external factors (e.g., if a participant was unavailable during the assessment week, the evaluation was moved to the previous or posterior week).

There is no validated questionnaire published in the literature to measure changes in sustainable diets through brief repeated assessments²⁶. We therefore used this pilot study to design and test a new questionnaire assessing healthy diets with low environmental impact. During the assessment weeks, participants were required to complete the questionnaire on a daily basis. It is a concise dietary questionnaire to evaluate the consumption of 10 pivotal food groups for a healthy diet with a minimal environmental footprint (the food groups covered in the questionnaire are shown in Table 1, and an English translation of the app-based questionnaire is shown in Additional File 5). This questionnaire was developed based on recommendations from authoritative bodies in the field of nutrition, including the EAT-Lancet Commission, the Food and Agriculture Organization, and the World Health Organization^{7,27–29}, and tailored for the Spanish context based on food availability and traditional dietary patterns.

For each food group, except for cereals and added fats, participants were asked to indicate the number of servings consumed during the assessed day, ranging from 0 to more than 5 servings, in increments of 0.5 servings (please see Additional File 5). The proportions of whole grains to total cereals, and virgin olive oil (as representative of unsaturated and non-refined added fats in our context) to total added fats were reported by participants. This ratio approach was chosen because recommended carbohydrate and fat amounts vary

Food groups	Scoring criteria ^a		Rationale
	0 points	1 points	
Meat, fish, and egg ^b	≥ 2 serv/d	≤ 1 serv/d	The consumption of 1 serving per day of meat, fish, or eggs (limiting red and processed meats to maximum 1 serving per week) seems to be compatible with a healthy diet within planetary boundaries ³⁹ . White meat, fish and eggs are good sources of high-quality protein, and blue fish of ω-3 fatty acids. Health benefits were observed when substituting red meat with any of those food groups, although their substitution by plant-based protein would lead the greater health benefits ⁷ . The environmental impact of white meat and eggs tend to be lower than that of red meat ³³ . The environmental impact of fish varies markedly depending on several aspects (e.g., the fishing or aquaculture techniques used, the species or fish stock from which it is obtained ^{17,42}). In any case, replacing those animal-based proteins by plant-sourced options reduce the environmental impact of diet; indeed, the lower the quantity of animal-based proteins in the diet, the lower the dietary environmental impact ^{36,37} .
Red and processed meat	≥ 2 serv/w	0 serv/w	The detrimental health effects of processed meat, and to a lesser extent of red meat, is well-established in the scientific literature. Red and processed meat consumption appears to be linearly related to total mortality and risks of other health outcomes in populations that have consumed it for many years ⁷ . Additionally, red meats (i.e., beef, lamb, pork) are the foods with higher environmental impact, several times higher than any other protein rich food ³³ . Thus, the optimal intake of red and processed meat might be 0 g/day in a healthy and environmentally sustainable diet ⁷ . The consumption of one serving of 100 g of red meat per week seems to be compatible with an environmentally sustainable healthy diet, but even small increases in consumption of red meat would not be compatible with environmental targets ⁷ .
Dairy products	≥ 2 serv/d	≤ 1 serv/d	There is no clear pattern of dairy products consumption and health outcomes. Although dairy products have been described as an essential source of calcium, this mineral could be obtained in an optimal level from a range of plant-based foods ⁷ . Additionally, dairy products are among the foods with the highest environmental impact ³³ . Climate change mitigation strategies encourage to reduce not only meat but also dairy products ^{34,40} . It has been proposed that optimal intake of dairy products within a healthy diet has to be at the lower end of the range 0–500 ml (milk equivalents). Indeed, the consumption of 2 servings of dairy products daily in an omnivorous diet would be out of the planetary boundaries ⁷ , and it has been recommended limiting their consumption to maximum 1 serving per day ³⁹ . Altogether, 1 point is allocated to one serving or less of dairy products per day, and 0 points to 2 or more servings per day.
Legume & derivatives	0 serv/d	≥ 1 serv/d	There is a large body of evidence reporting the health benefits of replacing animal foods with plant-based protein sources ⁷ . Additionally, legumes (including soy products if sustainably grown) are the protein rich foods with the lowest environmental impact ³³ . Altogether, legumes should be the main protein source in our diet, for human health and for that of the planet. At least one serving of legumes per day should be consumed in an environmentally sustainable healthy diet ⁷ . Thus, 1 point is allocated to one or more servings of legumes per day, and 0 points to no consumption.
Fruit & vegetables	0 serv/d	≥ 5 serv/d	Due to the health benefits and low environmental impact of fruits and vegetables, at least five servings of fruits and vegetable (in total) should be consumed per day ^{7,33} . Thus, 1 point is allocated to 5 or more servings per day, and 0 points to no consumption.
Nuts & seeds	0 serv/d OR ≥ 4 serv/d	1–2 serv/d	Daily consumption of nuts (including peanuts), foods rich in proteins and healthy fats, is recommended due to their health benefits ⁷ . Indeed, they have been suggested even as a replacement for red meat ⁷ . However, the quantity should be moderate, as some nut-tree crops are water, fertilizer, and pesticide intensive ³³ . Thus, 1 point is allocated to one or two servings per day, and 0 points to no consumption or 4 or more servings per day.
Sugary, salty and ultraprocessed foods ^c	≥ 2 serv/w	0 serv/w	The environmental impact of the group could vary significantly, from very low (e.g., plant-based pastries) to high (e.g., meat and cheese pizza) ³⁸ . However, the detrimental health effects of all the products gathered in this category is well established, and should be consumed as less as possible ²⁷ . Therefore, due to their neglected health effects, one point is allocated to no consuming and 0 point to more than 2 servings per week.
Sodas, juices and energy drinks	≥ 2 serv/w	0 serv/w	Intakes of added (such as those in sodas or energy drinks) and free sugars (such as those in fruit juices) should be as low as possible as part of a nutritionally adequate diet. The scientific evidence did not allow to set a tolerable upper intake level for dietary sugars ⁴³ . Diet soft drinks are neither a healthy option ⁴¹ . The environmental impact of this type of beverages is low ³⁵ . Because of their negative health effects, 1 point is allocated to no consumption, and 0 point to two or more servings per week.
Cereals	0	≥ 80% whole grains	The environmental impact of whole grains and refined grains could be considered mostly the same ³⁵ . On the other hand, because their health benefits, whole grains should be prioritized over refined versions ⁷ . Thus, 1 point is allocated to consume at least 80% of the grains as whole grains, and 0 point to no consumption.
Added fats	0	≥ 80% unsaturated unrefined oil	Unsaturated and non-refined oils, mainly virgin olive oil (extra or not) in our context, should be prioritized over other added dietary fats because of their health benefits ⁷ . Small amounts of animal-sourced fats could be tolerable in a healthy diet with low environmental impact if consuming animal-based foods, to avoid wasting that fats ⁷ . Thus, one point is allocated to at least 80% of virgin olive oil of the total added fats, and 0 point to no virgin olive oil consumption.

Table 1. Scoring criteria and rationale for each food group targeted. ^aEach item is continuously scored from 0 to 1 point, according to the average daily consumption over the assessed week. For instance, the scoring of fruits and vegetables was: 0 points for no consumption of fruit and vegetables, and 0.25, 0.5, 0.75, and 1 points for the average consumption of 1.25, 2.5, 3.75, and 5 or more servings per day, respectively. ^bInclude data of two items of the eating behavior questionnaire: (i) red and processed meats, and (ii) white meat, fish and eggs. ^cThis item gathered the consumption of highly processed foods or products high in sugars, salt or fats, such as biscuits, bakery or pastries (both home-made and industrial), sugary and salty snacks (e.g., candies, crisps), sugary dairy desserts (e.g., custard, flam, ice-cream), ready-to-eat meals (e.g., pizza, lasagne), among others.

according to individual energy needs, thus emphasizing healthy choices over quantity. To assist participants in answering the questionnaire, examples of specific food products gathered within the assessed food groups were available in the app³⁰, with examples of serving sizes using household measurements³¹, as well as instructions on how to calculate the proportion of whole grains and added fats (see Additional File 5). Participants received training in food group quantification at enrolment and during feedback sessions, if needed.

In terms of scoring procedure, we used the daily measures of these food groups consumption to design a composite score capturing the weekly environmental sustainability and healthiness of the whole diet (i.e., the daily consumptions were averaged at the weekly level to capture a weekly pattern of diet composition). A valid week was defined as having recorded values for at least two weekdays and one weekend day³². The average weekly consumption of each food group was scored from 0 to 1 point, with 1 point allocated to a consumption in line with the recommendations for a healthy diet with low environmental impact, 0 points for consumption exceeding the limits for such a diet, and a proportional score for an in-between consumption. Table 1 shows the scoring criteria and the rationale, supported by up-to-date scientific evidence^{7,17,27–29,33–43}. The total diet score

is the sum of that of each individual item, ranging from 0 (lowest adherence to an environmentally sustainable healthy diet) to 10 (highest -best- adherence).

Finally, to gain insights about potential changes in individual food groups beyond the overall weekly pattern of diets, raw daily food data (i.e., not averaged with a specific scoring procedure) were also analyzed (see the following sections).

Qualitative measures

Three individual semi-structured online interviews were conducted with each participant: at baseline, at the end of the intervention, and six months later (Fig. 1). The first interview aimed to further characterize participants' typical diets, going beyond the food group consumption reported in the eligibility survey. This involved exploring aspects such as specific food preferences, the times of day when certain food groups were consumed, and daily dietary routines, among others. Additionally, the interview sought to assess participants' knowledge of sustainable diets and their motivations for participating in the study. The second interview focused on the feasibility and acceptability of the intervention and the participants' perceptions of behavior changes. It explored additional behaviors relevant to a sustainable diet that were not addressed quantitatively, specifically food waste or any other behavior change towards dietary sustainability that participants considered relevant. The third interview explored barriers and facilitators related to behavior change, but participants eventually commented on feasibility, acceptability, and the effects of the intervention on eating behaviors. All interviews were conducted by the same researcher who led the feedback meetings (UF). They were carried out online, and were digitally recorded, anonymized, and transcribed verbatim. Audio files and transcripts were imported into MAXQDA 24 software⁴⁴, which was used for the qualitative data analysis. Further details on the interviews content and delivery can be found in the protocol of this study²¹.

Data analysis

Quantitative data

The feasibility and acceptability of the study, as well as the characteristics of the participants, were analysed with descriptive statistics.

Dietary changes were assessed at the group (i.e., nomothetic analyses) and individual (i.e., idiographic analyses) levels. At the group level, changes in weekly diet composition (i.e., composite score) were assessed using linear mixed regression models with a random intercept for individuals, weekly diet composition (i.e., composite score) as the outcome, the week number (weeks 1 to 46) as the independent variable, and the models were adjusted for age. Other adjusted models were tested when building the final model (i.e., adjusting for gender, incomes, education and total duration of feedback sessions), but the best statistical fit was obtained for age as the only covariate. We also analyzed women and men separately given the potential differences described in the literature between these two groups in terms of sustainable diets¹². Although we expected gradual changes in diets during the study (best characterized by the progressive effect of weeks), we also wanted to test the differences between each phase. Therefore, and as sensitivity analyses, the models were also run with a 3-category phase variable (baseline, intervention, and follow-up) as the independent variable. The phase score was calculated as the mean weekly score per participant for each phase.

We also performed dietary change analyses at the individual level. To maximise statistical power (see our pre-registered report²¹), we used daily individual food groups as an outcome instead of our weekly aggregated composite score (i.e., thus maximising the number of observations available per participant). Our initial intention was to use regression techniques similar to those employed to assess dietary changes at the group level²¹. However, the non-normal distribution of the individual food groups measured at the daily level made the use of linear models not suitable. As an alternative solution, we used Nonoverlap of All Pairs (NAP) analyses to quantify changes in each specific food groups between the baseline and follow-up phases. NAP is a non-parametric method that indicates the probability that a score drawn at random during the follow-up phase will exceed that of a score drawn at random at baseline (values between 0 and 100%, with 50% indicating no change)⁴⁵. To aid interpretability, NAP values were rescaled to values between -100% (all scores during the follow-up phase were lower than the lowest score at baseline) and 100% (all scores during the follow-up phase were higher than the highest score at baseline), with 0% indicating no change. NAP values above 72% were considered as large effect sizes⁴⁶.

Data were analyzed with the statistical software R version 4.3.2 (R Foundation for Statistical Computing) using the *nlme* and *scan* packages. The data and code used in this study are openly available on the Open Science Framework page of the project together with an html version of our analyses' outputs⁴⁷.

Qualitative data

Framework analysis was used to analyze the qualitative data. This is a thematic approach to the analysis of qualitative data from semi-structured interviews, as in our case⁴⁸. Based on the main themes of the semi-structured interviews, two researchers (UF, SF) developed the original codebook after a careful reading of the transcripts, and a third confirmed it (MLM). Disagreements between the researchers were discussed until an agreement was reached. One researcher then applied the codebook to the transcripts (MLM). After examining the patterns across codes, data on the topics addressed in the current study (i.e., feasibility, acceptability, and effectiveness) were comprehensively summarized by one author (UF) and subsequently confirmed by a second author (MLM). During this process, disagreements were discussed until a consensus was reached.

Results

Sample description, feasibility and acceptability

During the three-month open registration period, 94 individuals completed the eligibility survey, and 12 met the inclusion criteria (13%). Most participants (73/82, 89%) could not be included because they presented a baseline diet relatively aligned with the principles of sustainability. The 12 eligible individuals were invited and accepted to participate. All participants remained in the study until completion, resulting in a 100% retention rate (flowchart is shown in Additional File 6). Individual characteristics of the participants are shown in Table 2. Among the 12 participants, 7 were women and 5 were men, and the average age was 26 years.

Quantitative results for acceptability are provided in Table 2. All participants provided a score for every text message sent, therefore indicating that they have read every text message. The text messages received an average score of 84 points out of 100 for their usefulness, informative and motivating nature. Both quantitative and qualitative data indicated that participants particularly appreciated receiving recipes, and messages related to the environmental and socio-economic impacts of food (see additional file 7 for the descriptive statistics, and Table 3 and Additional File 8 for qualitative insights). Regarding the feedback sessions, nine participants participated in the three sessions offered, two participants attended two sessions and one participant only attended one session. On average, the participants spent 49 min attending feedback sessions. Regarding the assessment of food consumption, participants responded to 86% of the 105 food consumption questionnaires sent.

Qualitative insights on acceptability are presented in Table 3, with detailed data for each individual participant available in Additional File 8. The qualitative data revealed that the participants found the individual feedback sessions particularly useful for reflecting on the evolution of their diet and for the individualized advice they received. Indeed, half of them specifically highlighted these sessions as the most useful feature of the intervention. Overall, participants found the food consumption questionnaire clear, with enough information, easy to answer, and not time consuming. Nevertheless, some participants highlighted that the items targeting the proportion of whole grains and virgin olive oil should be reformulated, to provide the option of reporting “no consumption”, or predefined values of percentages instead of asking a specific amount. No major problems with the app were reported, although some improvements were proposed, such as the option of going back to change some previous answers within the same questionnaire, having a repository where they could find the information sent through the text messages along the study, showing a graph that allows them to follow their diets’ evolution over time, and receiving a personalized report or notification with the adequate or inadequate consumption according to their dietary questionnaires (see Table 3 and Additional File 8). The frequency of text messages, feedback sessions and prompts to answer food consumption questionnaires were found to be adequate.

Effects of the intervention on dietary composition

Results from the group level analyses indicated a significant linear weekly increase in the composite score of 0.04 points (95% CI 0.03, 0.05) (Conditional $R^2 = 0.55$; $F(1,157) = 66.58$; $p < 0.001$); in other words, the score of sustainable diets improved of 0.04 points on our 10-point scale for every week in the study. Using phase (i.e., baseline, intervention, and follow-up) as the independent variable, the models highlighted significant increases of 1.25 (95% CI: 0.83, 1.66) and 1.85 points (95% CI 1.43, 2.28) compared to baseline for the intervention and follow-up phases, respectively (Conditional $R^2 = 0.57$; $F(2,156) = 37.50$; $p < 0.001$). Average (standard deviation) score at baseline was 3.53 (0.75), during the intervention 4.80 (1.05) and during the follow-up phase 5.38 (1.04), the score being bounded between 0 and 10 points. Stratified analyses by sex showed similar findings for women and men. Figure 2 shows the changes in the composite scores for each participant.

Figure 3 highlights the individual changes in the consumption of the specific food groups between the baseline and follow-up phases. Most participants presented a significant increase in their fruit and vegetable consumption (11 participants out of 12, with four presenting large effect sizes). Seven participants significantly reduced their intake of red and processed meat and their consumption of sugary, salty and ultra-processed foods (with two participants presenting large effect size for red and processed meat). Half of the participants significantly increased their proportional intake of whole grains (two participants presenting large effect sizes) and virgin olive oil (one participant presenting large effect size). A minority significantly increased their consumption of legumes (five participants, two presenting large effect sizes), as well as nuts and seeds (five participants). Four participants significantly decreased their intake of dairy products (all of them showing large effect sizes) and sodas (one presenting large effect size). One participant significantly reduced their consumption of the composite group gathering white meat, eggs and fish. No participants exhibited significant dietary changes in an unexpected direction. Additional File 9 displays the individual time series for each participant and food group, and group level results can be seen in Additional File 10.

Changes in other key behaviors for dietary sustainability were assessed qualitatively (see Table 4 for examples of comments related to each behavior, and Additional File 11 for further details at the individual level). Regarding behaviors for environmental sustainability, most participants (9/12 participants) did not typically waste food before entering the study. Nevertheless, two of them reported to feel even more conscious about the relevance of not wasting food after the intervention. The other three participants indicated that they did not pay attention to food waste before the intervention, but that being in the study increased their awareness of its relevance and helped them to reduce food waste. Three participants mentioned that the intervention made them seek in-season products when buying fresh food, and another three participants reported avoiding food packaging as much as possible, especially plastic, following the intervention.

Regarding the socio-economic aspects of food (see Table 4 and Additional File 11), four participants reported that the intervention encouraged them to routinely purchase food from small markets (another one already used to do it before the study), three started to actively seek fair-trade coffee (another one already mentioned to do it before the study), and one specifically mentioned that, because of the intervention, they were committed to

ID	1	2	3	4	5	6	7	8	9	10	11	12
Sociodemographic characteristics												
Gender	Male	Female	Female	Male	Female	Female	Female	Male	Male	Male	Female	Female
Age (years)	26	26	49	18	35	32	33	34	42	24	39	26
Education	Master	Master	Doctorate	Secondary	Doctorate	University degree	Doctorate	Secondary	Master	Master	Master	Master
Incomes (of the family unit after taxes per month)	1500–1999 €	2000–2999 €	3000–3999 €	1500–1999 €	2000–2999 €	1500–1999 €	4000 or more €	2000–2999 €	4000 or more €	1000–1499 €	1500–1999 €	2000–2999 €
Engagement with the study												
Messages read (out of 44)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)	44 (100%)
Eating behavior questionnaires answered (out of 105)	105 (100%)	88 (84%)	74 (70%)	103 (98%)	101 (96%)	89 (85%)	95 (81%)	89 (85%)	98 (93%)	59 (56%)	104 (99%)	77 (73%)
Number of feedback sessions attended (out of 3)	3 (100%)	2 (67%)	1 (33%)	3 (100%)	3 (100%)	3 (100%)	3 (100%)	3 (100%)	3 (100%)	2 (67%)	3 (100%)	3 (100%)
Total time spent on the feedback sessions (minutes)	37	40	35	38	58	53	58	50	67	31	74	48

Table 2. Baseline characteristics of the participants (n = 12), and acceptability of the intervention and evaluation procedures.

Domains	Main findings	Examples of comments
Text messages	Participants really appreciated receiving recipes and other practical tips that they can implement in their daily routines. Even they mentioned they would like to have received more notifications of this type. Participants also liked messages related to the food environmental impact and socio-economic aspects, and those were considered novel and stimulating. On the other hand, two participants said that they were expecting (and probably would have preferred) tailored notifications The frequency of receiving text messages in the app (twice per week, Tuesdays and Fridays), and the time spent on reading them was considered adequate. Only one participant said that some notifications were too long	Id8: "One thing to highlight: the recipes. The fact of receiving those tips, those ideas to make small changes or recipes applicable in the day to day, which can be repeated. It's a starting point. That's a big help." Id9: "The notifications that explained the real environmental impact of food. I've also found recipes interesting. I was also happy to see what kind of dishes I could cook with legumes. That also gives me ideas." Id3: "I thought the messages would be more tailored, like an analysis of my responses. And I didn't find them individualized, I found them generalists [...] I could have found that information by any other means."
Individual feedback sessions	Participants found the feedback sessions really useful to reflect on the evolution of their diet, resolve any doubt they could have, and because the individualized advice and tips they received. Indeed, six participants specifically highlighted those sessions as the most useful feature of the intervention The frequency of having the feedback sessions (every one month and a half approximately) was considered adequate, as there was enough time from one to the other to implement the provided advice	Id10: "It seems to me that it has served me even more than the messages, because we were targeting what I didn't know or something I thought was in a way and it wasn't. Some things suddenly arise and then you clarify." Id3: "I think it's [frequency] okay. I wouldn't shorten it. That is, to do it more often, because I needed some time after the feedback to adapt my food habits."
Dietary questionnaire	Participants found the dietary questionnaire clear, with enough information, easy to answer and no time consuming. However, 2 participants said that responding it during 14 days in a row during the baseline period was very intense. Nevertheless, from there, as the frequency was reduced and they had got used to it, they did not have that feeling anymore. Only one participant said that answering the 7 days within a week was burdensome Seven participants highlighted that responding the questionnaire was useful to be aware about their food consumption. Indeed, four participants mentioned that the frequency could be increased to every other week during the intervention and follow up periods to pay more attention to their diet On the other hand, several participants pointed that the items targeting the proportion of whole grains and added fats should be reformulated, providing: the option of reporting "no consumption"; predefined values of percentages instead of asking participants a specific amount; and information about how to quantify unknown oils or fats added at the restoration level	Id8: "The questionnaire is understandable. It is not something difficult, it is easy to answer [...] I think it is very complete, very accessible for anyone to answer." Id1: "Just doing the daily questionnaire every three weeks, you're realizing if you're eating a lot of one thing or very little of another." "I would rather have it for more weeks to get a better idea of what I eat" Id12: "There were days that I didn't use oil, for example, what should I register?"
App	Two participants reported that some links sent through the mobile application did not work properly. One said that the notifications and eating behavior questionnaire reception was not alerted in her app (she routinely checked the app to find if she had received any notification or questionnaire). Beyond that, no major problem with the app was reported. Besides participants found the app simple to use, they suggested some improvements, such as the option of going back to change some previous answers within the same questionnaire, having a repository where they could find the information sent through the notifications along the study, showing a graph that allows them to follow their diets' evolution over time, and receiving a personalized report or notification with the adequacy or inadequacy of their food consumption according to their eating behavior questionnaires along the last week	Id5: "In the app, the possibility of modifying the answer on previous items of the same questionnaire." Id6: "I would put a repository where I could go back to all this [the messages sent]." Id9: "It might help to visualize my progress [...], with some bars to see my evolution, maybe." Id6: "Alerts could be implemented 'This week you have eaten too much meat' or 'You have not eaten enough vegetables'. The negative, but also the positive. 'You've eaten more vegetables this week.'"
Overall study	Participants liked been involved in the study. All of them would recommend relatives and friends to take part of it, mainly to increase their awareness about their own diet and the necessity of following a sustainable diet	Id11: "I'd recommend it. I believe that it can help them to be aware of what they are consuming, of the impact that this hyperconsumption that we have in the society causes to the planet. If we multiply it [the positive effects of being in the study] by many people, this will generate a positive impact."

Table 3. Qualitative findings regarding acceptability of the intervention and evaluation procedures.

ordering delivery foods only from places with fair riders' conditions. Four participants expressed a new focus on seeking locally grown food. Two participants emphasized that they started to buy free-range eggs because of animal welfare concerns. On the other hand, four participants acknowledged the importance of considering working conditions in the food system or buying directly from producers, but did not change their habits in this regard.

All participants noted that participating in the study enabled them to increase their knowledge about sustainable diets (e.g., breaking down nutritional myths and broadening their knowledge of the different dimensions of dietary sustainability), as long as they were more aware of their food consumption.

Discussion

This pilot study examined the feasibility, acceptability, and efficacy of an innovative eating behavior change intervention promoting sustainable diets over a year. Except for the recruitment, where only 13% of the interested individuals met our inclusion criteria, the intervention feasibility was underscored by a notable 100% retention rate. Moreover, the intervention and evaluation were well-received by participants and exhibited a high level of engagement. In addition to its viability, the intervention proved effective in fostering positive shifts in sustainable dietary behaviors for the majority of the participants. Over time, discernible changes were observed in food consumption at the group level, during the intervention, and 24 weeks later. Increases in the consumption of fruits and vegetables, as well as reductions in red and processed meats and sugary, salty, and ultraprocessed foods, were the most widely observed dietary changes among participants. Qualitative findings pointed out improvements in other behaviors crucial for dietary sustainability, including a reduction in food waste and increased awareness of environmental and socio-economic factors, influencing food choices.

Recruitment

Regarding feasibility, only 13% of individuals who completed the eligibility survey met our inclusion criteria. Most (73 out of 82 excluded individuals) were left out because they presented high baseline scores for sustainable diets, leaving minimal scope for improvement. This issue could be addressed in future studies by either adopting

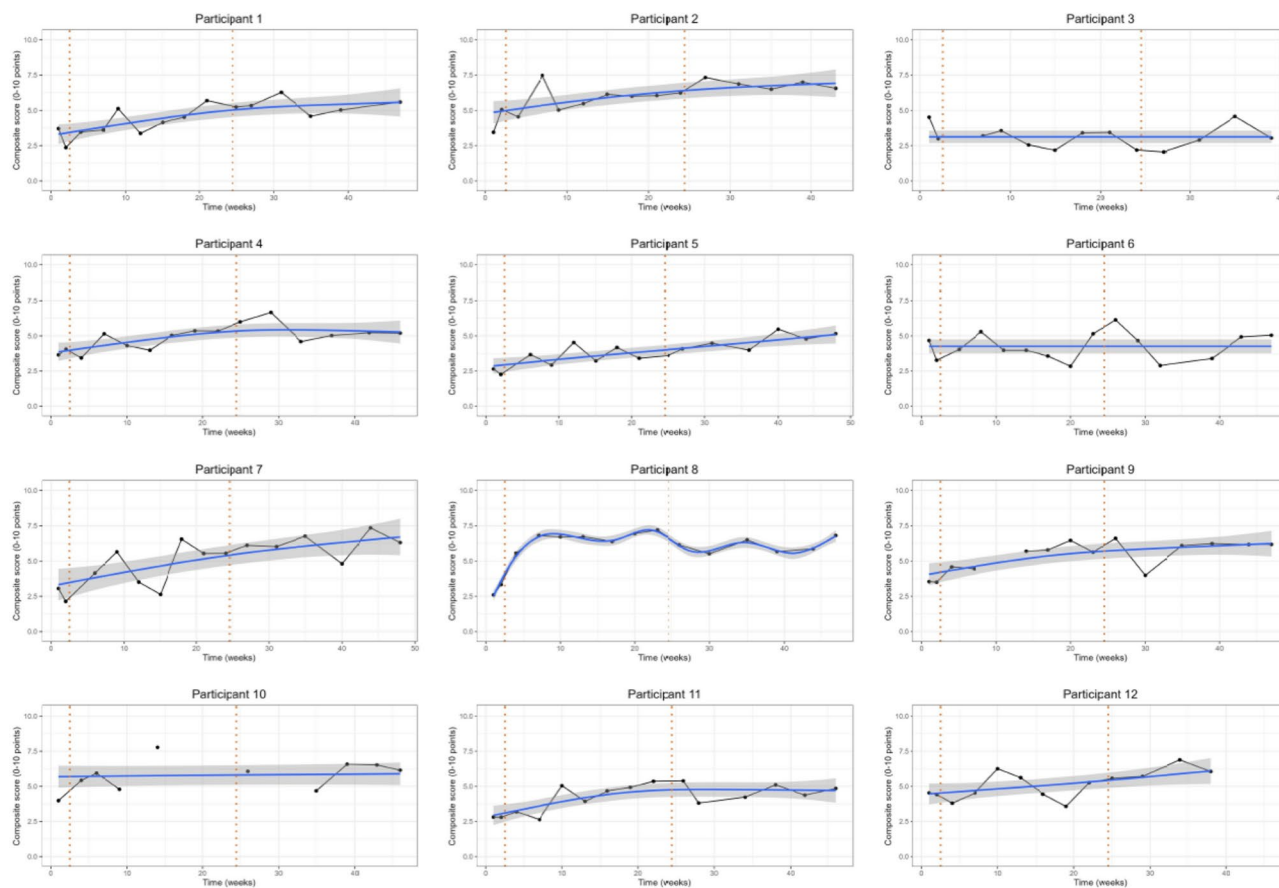


Fig. 2. Dietary weekly score at the individual level over the course of the study. Note: The composite score ranges from 0 to 10, with 0 representing the least optimal diet and 10 indicating the most optimal diet in terms of healthiness and environmental sustainability. Vertical dashed lines represent the transitions between the baseline and intervention phases (first dashed line), and between the intervention and follow-up phases (second dashed line).

a less stringent threshold—assuming that those with higher scores can still optimize their behaviors—or by revising our recruitment strategy. Relying on email communication within a global health research institution, social media and word-of-mouth as our primary means of reaching potential participants may have limited participant diversity, resulting in most potential participants presenting high sustainable diet scores⁴⁹. Efforts in future large-scale iterations should aim to diversify recruitment avenues, reaching a broader and diverse group of people and therefore increasing recruitment capacity. Additionally, depending on future interventions' scope, it could be important to engage more deprived and less educated samples of participants as these individuals might be less likely to benefit from existing interventions delivered via digital or mobile means^{50,51}. Future recruitment strategies could be improved by using social media with targeted advertising towards harder to reach individuals, or collaborating more closely with relevant institutions, such as faculties, health providers, or NGOs, to reach a more diverse sample^{52–54}.

Engagement with and acceptability of the study procedures

Despite the unique sampling frequency of this study making direct comparisons with previous research difficult, both qualitative and quantitative data showed positive outcomes for both the intervention and evaluation features used in this study. First, regarding the text messages, all were read and received an average score of 84 out of 100 for their usefulness, informativeness, and motivational value. Second, regarding the feedback sessions, all participants except three attended all three sessions. Results from the qualitative interviews also revealed that half of the participants (6 out of 12) perceived the feedbacks as the most useful intervention feature, which is in line with prior research indicating that digital intervention users expect to receive feedback on their behaviours⁵⁵.

Regarding the evaluations, participants completed an average of 86% of the 105 food consumption questionnaires, with qualitative data revealing high overall satisfaction with the questionnaire and relative procedure (i.e., implementation in the app, sampling frequency). Together with the design of our questionnaire, the good response rate might have been positively influenced by the monetary incentives offered (10 euros per valid week of measure⁵⁶). However, three participants indicated that financial incentives were unnecessary

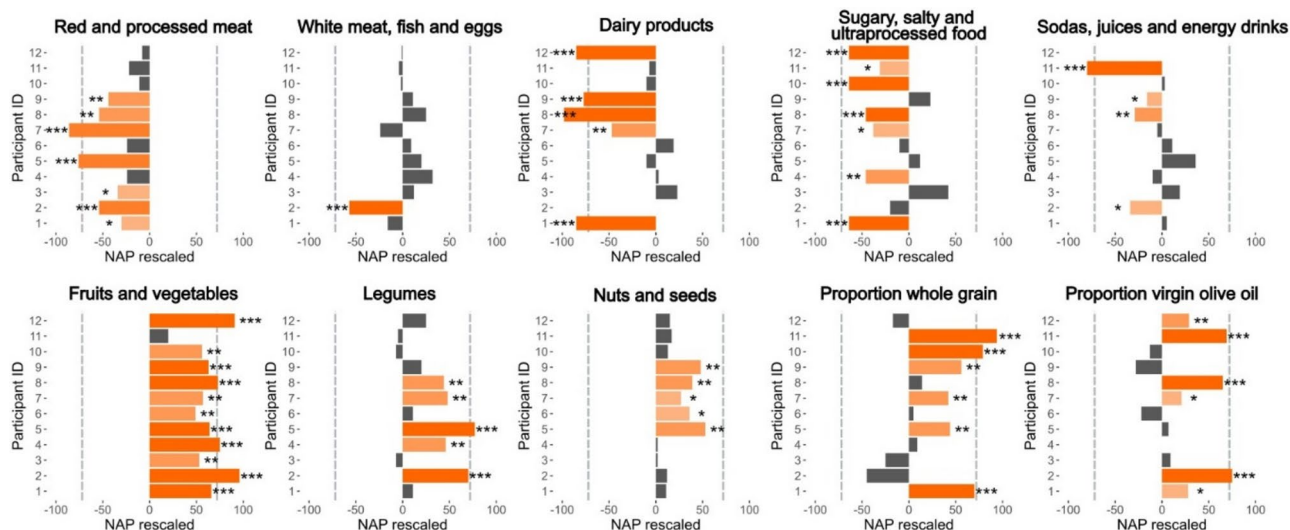


Fig. 3. Dietary changes across targeted food groups at the individual level, comparing follow-up periods to baseline. Note: NAP Non-overlap of all pairs. Positive values indicate an increase in consumption, while negative values indicate a decrease. A value of 0 signifies no change. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Grey bars indicate no significant changes, the lightest orange bars represent significant changes with p-values between 0.01 and 0.05, the medium orange bars represent significant changes with p-values between 0.001 and 0.01, and the darkest orange bars indicate significant changes with p-values less than 0.001. Dashed lines represent large effect sizes (NAP values above 72%).

Outcomes	Examples of comments
Reduced food waste	Id2: “The truth is that I’m much more conscious. I mean, I used to be, too, and I was trying to make it [food waste] as small as possible. But I don’t know, somehow I’m more aware.” Id9: “I did focus more on consuming those foods that I saw that were going to spoil in the fridge, or instead of cooking, I say ‘why don’t I try to finish the leftovers? Or why not these leftovers that I left yesterday for lunch or dinner?’”
Increased in-season products consumption	Id11: “This is something that used to be difficult to me before because I’m not from here. From where I am, we have everything all year around. Then here it was a little bit harder. But now I know the in-season products, such as now cherries, and strawberries too.”
Reduced food packaging	Id8: “We do not go to the supermarket to avoid buying it [food] in plastic containers.” Id11: “I try, of course, to buy without so many plastic containers. And I avoid even using a compostable bag in the [supermarket name], for instance for tomatoes. Now tomatoes go without bag and so, I avoid all these plastics.”
Increased consideration of socio-economic aspects	Id2: “I’ve definitely noticed a change. I don’t buy all that fruit and vegetables anymore at the supermarket. So in this sense I do go to the fruit shop, much more than I did before. I mean, I tried to support local businesses and make the system more sustainable” Id3: “I have tried to go more to farmer markets. Yes, I have tried, but of course, it is also not comfortable, you can only go on Saturday morning. I don’t find it accessible, the price also skyrockets. But at least I try to eat products produced locally and in-season.” Id5: “I had already started to buy more local food, more in bulk, but it is true that this has been encouraged a lot [during the study] and I am more aware, thanks to the feedback meetings, to take into account working conditions, take into account where they come from and also not only where they come from, but also take into account the social factor that represents where the food we eat comes from.”
Increased consideration of animal welfare	Id3: “Regarding eggs, I now always buy from number one [free range hens]. Additionally, I’ve achieved that the fruit store at my neighborhood, which sells eggs in bulk, switch from stocking code three (cage-hen) eggs to code one (free-range) eggs.”
Increased knowledge	Id12: “I did not know that dietary sustainability also considers how people who are involved in the system are treated. I thought it was exclusively related to the environment, but not to also take people into account. [...] I thought juices were healthy and I realized that besides being natural, they have a lot of sugars and it is much better to eat the whole fruit. Or legumes, I had no idea they were so beneficial.”

Table 4. Examples of qualitative findings on behavior changes in key practices for sustainable diets observed during the study.

given the personal benefits they gained from participating in the intervention. If these incentives could pose scalability challenges for future studies, potential solutions include decreasing the monetary compensation for valid assessments, adjusting the sampling frequency of food consumption to every four, five, or six weeks, and further reinforcing the self-monitoring nature and the personal benefits derived from these evaluations (i.e., participants indicated that they would have preferred to use the questionnaire even more frequently, and have access to their responses throughout the study, as a way to track their own behavior changes over time; see Table 3 and Additional File 8).

Although the overall dietary assessment was positively perceived by the participants, potential improvements were suggested. Notably, three participants recommended to add the option to report “no consumption” for items assessing the proportion of whole grains and virgin olive oil. Implementing their suggestions could help participants provide more accurate data in future studies.

Effect of the intervention

There was a small but significant linear improvement in the composite score over the study period at the group level, with the highest scores observed during the follow-up phase. As hypothesised, this suggests that dietary change in the study was likely progressive rather than abrupt⁵⁷. This trend aligns with the iterative nature of our intervention, particularly the feedback sessions based on previous dietary measures, and the cumulative information delivered through text messages. Together, these elements may have supported gradual improvements⁵⁸, although neither our study design nor analytical strategies aimed to test the specific influence of these two interventional features on dietary change.

Text messages

The content of the text messages likely partly influenced the observed patterns in food group consumption depicted in Fig. 3. Specifically, the messages highlighted the environmental impact of animal products, with a strong emphasis on red and processed meats and dairy products, while comparatively less attention was given to white meat, fish, and eggs. Mirroring the nature of the text messages, seven participants significantly reduced their consumption of red and processed meats, and five reduced their dairy intake, whereas only one participant decreased their consumption of white meat, fish, and eggs.

Furthermore, our text messages fostered a comprehensive understanding crucial for adopting dietary sustainability beyond diet composition. These messages addressed a wide range of environmental and socio-economic issues, such as reducing food waste, choosing minimally packaged and in-season products, and considering socio-economic aspects and animal welfare when making food purchases—topics not deliberately targeted in the feedback sessions. Although not quantitatively assessed, several participants reported improvements in these behaviors following the intervention (see Table 4 and Additional File 10).

As further improvements of this intervention feature, participants particularly appreciated the recipes. As these comprised only 10% of the messages sent, future interventions could increase the number of recipes provided. Indeed, providing practical tips in addition to theoretical knowledge about dietary guidelines is key to promoting dietary behaviour change⁵⁹. Additionally, participants pointed out that having a repository of all the received messages in the app would be useful for keeping this information available during the intervention. Enhancing the layout of these messages could be also crucial for effectively conveying the information and engaging less motivated users. A visually appealing design can capture attention and encourage interaction, especially for users who may otherwise lack interest.

Tailored feedback sessions

Results from the qualitative analyses showed that participants perceived the individual feedback sessions as the most valuable aspect of the intervention (6 participants out of 12; refers to Table 3 and Additional File 8). This finding aligns with existing literature, which emphasizes the effectiveness of personalized feedbacks for eating behavior change^{58,60,61}. This also strongly suggests that this intervention feature should be maintained in future iterations of the study. Acknowledging that this could be the most difficult feature to scale-up, and based on the feedback provided by our participants, a potential solution could involve integrating automated, algorithm-based, individual feedbacks using the data gathered from the dietary questionnaires. Nonetheless, the current evidence remains inconclusive on whether algorithm-generated feedback is as effective as individualized feedback delivered by a trained nutritionist on dietary change⁶². If future randomized controlled trials prove algorithm-generated feedback effective in promoting sustainable diets, an intervention based on repeated dietary assessments could be relatively easily implemented via a specific app, as it has already been done for other behaviors (see for example⁶³). Human-generated feedback could then be reserved for specific situations depending on the project's human and financial resources, and/or for the participants not responding to the first phases of the intervention.

The food consumption questionnaire as a self-monitoring tool

Although our intensive longitudinal measures of food consumption did not aim at influencing behavior change, it is possible that the evaluations acted as a self-monitoring tool in this study^{64,65}. Indeed, seven participants mentioned that answering the dietary questionnaire was useful to self-monitor their diet, and four individuals even suggested to increase the number of evaluation weeks to further have the opportunity to monitor their food consumption (see Table 3 and Additional File 8). Future iterations of this study could enhance this self-monitoring feature by, for example, showing a graph that allows participants to track their dietary evolution over time, as suggested by some participants (see Table 3 and Additional File 8).

Strengths, limitations and perspectives

This pilot study represents one of the first behavior change interventions aiming at promoting sustainable diets in a holistic way. While there have been previous attempts to promote such dietary patterns (see for example^{15,16}), our study offers a broader scope, considering not only diet composition, but also other behaviors essential for targeting environmental and socio-economic aspect of sustainable diets. Another strength of this study resides in the longitudinal, quantitative and qualitative, data collected, allowing us to deepen our understanding of the study's feasibility and impact. The brief and continuous assessment implemented through the app provided a high-resolution view of the changes in food consumption, yielding useful information for improving our understanding of the overall behavior change process in comparison with studies using traditional, low-resolution measurement paradigms (eg. pre- and post- intervention).

This study has also several limitations. The first limitation of our study is the recruitment strategy, which likely led to a relatively homogenous—particularly in terms of socioeconomic level—and motivated sample. Consequently, alongside the small sample size, the results cannot be generalized to a broader population.

Future iterations of similar studies should invest more resources for the recruitment strategies in order to include more diverse populations (i.e., including individuals from lower socio-economic backgrounds). Second, the fact that we decided to use a custom, non-validated, questionnaire and scoring procedure to measure our main outcome implies that results regarding the intervention's effect on behaviors should be taken cautiously. The rationale behind using this custom tool, rather than relying on more classic food frequency questionnaire, lies in (i) our willingness to capture dynamic, repeated, and in-context changes in sustainable diets, making the utilization of available food frequency questionnaires not relevant, and (ii) the pilot nature of this study, which also aimed at pre-testing our questionnaire before running a proper validation study which is ongoing. Preliminary findings on the validation study indicate initial validity of this tool to assess healthy diets with low environmental impact⁶⁶. Third, the blended nature of this study, together with its specific design, precludes to test the specific contribution of each interventional features (i.e., text messages, feedback sessions and self-monitoring via the food consumption questionnaire) towards behavior change. This could be approached in future with appropriate study designs^{67,68}. Fourth, the qualitative evaluation of the intervention's effect was conducted through interviews that specifically targeted diet composition and food waste, but just broadly addressed other key sustainable behaviors (e.g., opting for minimally packaged or in-season foods). To fully capture the intervention's effect on those behaviors, it would be relevant to (i) refine the interviews' structure to deliberately target changes in these behaviors, and (ii) design questionnaires to provide quantitative measures of these behaviors. Finally, in the long run, other challenges could be addressed regarding scalability, such as: the cultural adaptation of this intervention to different countries, cultures, and languages; transitioning the focus from individuals to households; and, implementing a relatively similar version of this intervention in more inclusive contexts, such as public health offices or healthcare centers.

Conclusion

This pilot study demonstrates that a blended digital intervention can effectively promote sustainable diets in a holistic manner. It provides valuable insights for the design, optimization, and implementation of future digital interventions aimed at facilitating individual behavior change in more diverse and representative samples. Looking ahead, a more refined and enhanced version of the intervention, ideally through a randomized controlled trial, should be tested in a larger and more diverse population to further validate its effectiveness and generalizability.

Data availability

The datasets generated and analyzed during the current study are available in Open Science Framework: <https://osf.io/6scft/>

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Author contributions

Protocol design: UF, SF, PB, AB, VA-S, LMK, GC; Materials and tools development: UF; Implementation and data collection: UF; Supervision: GC; Quantitative data analysis: UF, JB, GC; Qualitative data analysis: UF, ML-M, SF. Writing first manuscript: UF; Manuscript review: all authors; Approval of the final manuscript: all authors.

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

The research protocol of this project has been approved by the Ethics Board *Comité de Ética de la Investigación con medicamentos del Parc de Salut MAR* (number 2022/10304/I) on October 19th, 2022, and was published before starting the implementation, after having been peer-reviewed²¹. All research was performed in accordance with the Declaration of Helsinki. Participants signed the informed consent form before being enrolled in the study.

Additional information

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