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Original Research

Impact of mediterranean diet promotion on environmental sustainability: a longitudinal analysis

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A R T I C L E I N F O

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A B S T R A C T

Objective: This article aims to estimate the differences in environmental impact (greenhouse gas [GHG] emissions, land use, energy used, acidification and potential eutrophication) after one year of promoting a Mediterranean diet (MD).
Methods: Baseline and 1-year follow-up data from 5800 participants in the PREDIMED-Plus study were used. Each participant's food intake was estimated using validated semi-quantitative food frequency questionnaires, and the adherence to MD using the Dietary Score. The influence of diet on environmental impact was assessed through the EAT-Lancet Commission tables. The influence of diet on environmental impact was assessed through the EAT-Lancet Commission tables. The association between MD adherence and its environmental impact was calculated using adjusted multivariate linear regression models.
Results: After one year of intervention, the kcal/day consumed was significantly reduced (−125,1 kcal/day), adherence to a MD pattern was improved (+0,9) and the environmental impact due to the diet was significantly reduced (GHG: −361 g/CO2-eq; Acidification:-11,5 g SO2-eq; Eutrophication:-4,7 g PO4-eq; Energy use:-842,7 kJ; and Land use:-2,2 m2). Higher adherence to MD (high vs. low) was significantly associated with lower environmental impact both at baseline and one year follow-up.
Meat products had the greatest environmental impact in all the factors analysed, both at baseline and at one-year follow-up, in spite of the reduction observed in their consumption.
Conclusions: A program promoting a MD, after one year of intervention, significantly reduced the environmental impact in all the factors analysed. Meat products had the greatest environmental impact in all the dimensions analysed.

Introduction

In recent years, greater consideration is being given to the impact that diet can exert on the health of the planet. Actual eating behaviour and food choices can affect to the production, transport, and marketing. These factors are related to the increase of for greenhouse gas emissions (GHG),[1,2] directly related to global warming.[3] Agriculture and food systems are estimated to be responsible for 19–29% of GHG,[3] as they use water-polluting substances and use approximately half of the planet's ice-free surface as farmland or grasslands.[4] Moreover, climate change can impact foods through decreasing the quantity, biodiversity, and nutrient content.[5]

With the rapid increase in world population, estimated to rise from 8 billion today to about 10 billion by 2050,[6] an increase in global food production is projected and subsequently implications for its impact on the environment.

Considering that different types of food may greatly differ in terms of environmental impact, dietary patterns become relevant not only in terms of health, but also in their relationship to environmental sustainability.[4,7]

One of the most studied dietary patterns is the Mediterranean diet (MD), recognized for its important benefits for cardiovascular health and the prevention of chronic diseases.[8–13] This dietary pattern is characterized by a high consumption of vegetable products and monounsaturated fatty acids (mainly from the olive oil); a moderate intake of fish; a low-moderate consumption of dairy products, poultry, and meat; and a moderate intake of wine with meals.[14]

Since the DM pattern shares characteristics with other sustainable diets characterized by a low consumption of animal products and, in addition, promotes biodiversity and local cultural heritage,[15] a DM promotion programme is expected to have beneficial effects on environmental sustainability and greenhouse gas production. However, there are hardly any studies that analyse the actual impact of the diet on the environment. The aim of this study was to estimate the effect of an intervention promoting an MD in a cohort of Spanish older adults with overweight/obesity and metabolic syndrome after one year of follow-up, on five environmental indicators: GHG emissions, land use, energy use, acidification, and potential eutrophication. The secondary aim of this study was to estimate differences in environmental impact according to the adherence into MD.

Methods

Study design

This longitudinal study has been conducted with data collected at baseline and after one year of intervention from participants included in the PREDIMED-Plus trial. This is a multicentre, randomized controlled 8-year trial, carried out in Spain in the context of primary prevention of cardiovascular disease in overweight and obese adults with metabolic syndrome. Participants were randomly assigned to one of two groups: an intensive weight-loss intervention group (based on hypocaloric MD, individualized physical activity promotion, and behavioural support) or a control group, which included unrestricted-energy MD promotion and traditional health care. Detailed information is included in the study protocol[16,17] and is available on the following website http://predimedplus.com. This trial was registered on July 24, 2014, in the International Standard Randomized Controlled Trial (ISRCT; http://www.isrctn.com/ISRCTN89898870).

Study population

From October 2013 to December 2016, 9677 people were contacted, of whom 6874 participants from 23 centres in Spain were included in the trial. The inclusion criteria were men between 55 and 75 years of age and women between 60 and 75 years of age; a BMI of ≥27 and <40 kg/m2 and meeting at least three criteria for metabolic syndrome established by the International Diabetes Federation and the American Heart Association and the National Heart, Lung, and Blood Institute.[18]

For the present study, participants who had not completed the Food Frequency Questionnaire (FFQ) at one of the two visits (at baseline or 1-year of intervention) and those who had extreme total energy intakes (<500 or >3500 kcal/day in women or <800 or >4000 kcal/day in men) were excluded.[19] A total sample of 5800 participants was evaluated in this secondary analysis (Fig. 1).

The study protocol complied with the ethical standards of the Helsinki Declaration[20] and was approved by the Research Ethics Committees of all recruiting centres. In addition, all participants signed an informed consent form upon entry into the study.

Variables and data collection

Dietary assessment was carried out using a validated semi-quantitative 143-item food frequency questionnaire (FFQ) for the Spanish population.[21–23] This questionnaire was completed upon entry into the program and at one year of intervention. The FFQ collects information on the foods consumed by the participant during the year before the interview. It includes nine response options ranging from never or almost never to more than six times a day. Nutrient and energy intake was calculated by multiplying the indicated frequencies of consumption by the weight of the standard serving size. Nutrient information was derived from Spanish food composition tables.[24,25]

Adherence to MD was calculated according to the Dietary Score (DS) index, created by Panagiotakos,[26] which includes 11 food groups (vegetables, legumes, fruits, fish, whole grains, potatoes, olive oil, poultry, dairy products with fat, red meat, and alcohol) and resulted in a score ranging from 0 to 55. This index classifies adherence by tertiles, the first corresponding to a low adherence and the third to a high adherence. Based on the information obtained in the FFQ, foods were grouped according to the DS criteria in terms of group classification and quantity eaten (servings/month).

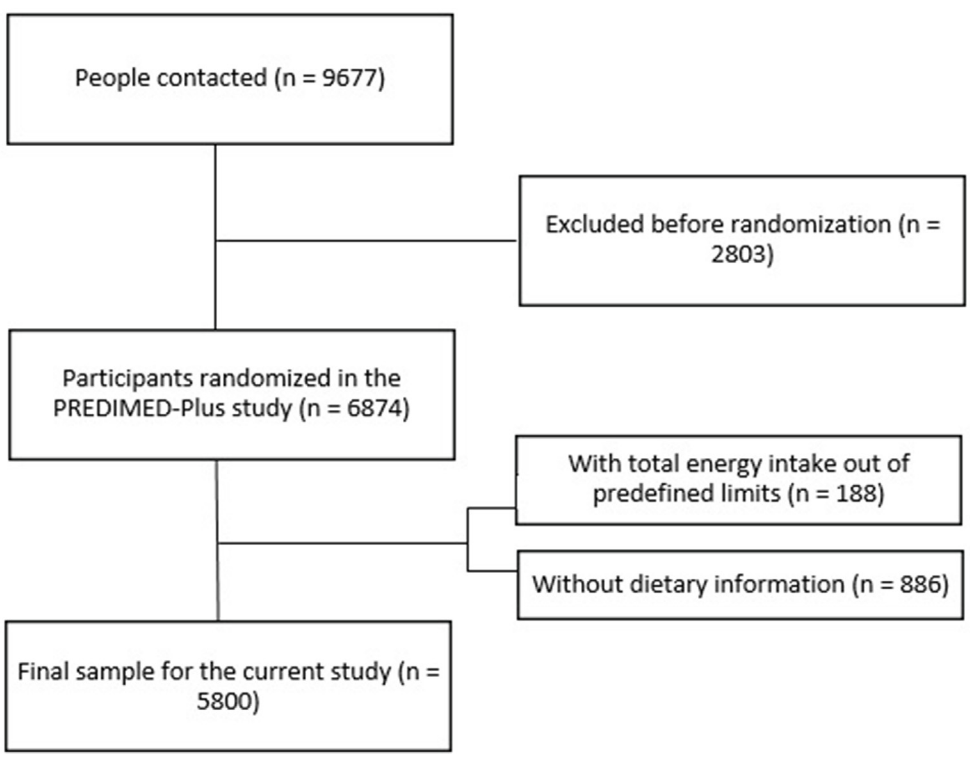

Fig. 1. Participant flowchart.

Table 1
Baseline general characteristics of the study sample according to tertiles of adherence to MD using the Dietary Score (DS).

	Overall (n = 5800)		Tertiles DS (points)			
	n	%	Low (0–31)	Medium (32–35)	High (36–55)	*P-value*
Sex						0.150
Men	3005	51.81	1191 (55.94%)	868 (45%)	946 (54.31%)	
Women	2795	48.19	938 (44.06%)	1061 (55%)	796 (45.69%)	
Educational level						**0.002**
Primary or less	2854	49.21	1087 (51.06%)	976 (50.60%)	791 (45.41%)	
Secondary	1658	28.59	603 (28.32%)	518 (26.85%)	537 (30.83%)	
University	1288	22.21	439 (20.62%)	435 (22.55%)	414 (23.77%)	
Age (years)						**0.042**
≤64	2670	46.03	1031 (48.43%)	860 (44.58%)	779 (44.72%)	
65–70	2267	39.09	802 (37.67%)	777 (40.28%)	688 (39.49%)	
≥71	863	14.88	296 (13.90%)	292 (15.14%)	275 (15.79%)	
BMI (kg/m^2)						**0.008**
<30	1580	27.24	557 (26.16%)	530 (27.48%)	493 (28.30%)	
≥30 y < 35	2858	49.28	1034 (48.57%)	941 (48.78%)	883 (50.69%)	
≥35	1362	23.48	538 (25.27%)	458 (23.74%)	366 (21.01%)	

Sociodemographic data, anthropometric measurements, dietary, and lifestyle habits were collected by trained PREDIMED-Plus staff at the baseline.

Estimating the environmental footprint

Based on information collected in the FFQs, GHG emissions (grams of CO2-equivalents), land (m^2) and energy use (Kilojoules (kJ)), and acidification (grams of SO2-equivalents) and eutrophication potential (grams of PO4-equivalents) of each food were estimated according to the EAT-Lancet Commission tables[27] (Environmental footprint values of each food available in supplementary material). These calculation were performed as follows: (1) All FFQ foods included in the EAT-Lancet Commission tables were included (i.e., 102 food items), with 41 food items excluded due to a lack of available information; (2) when it came to elaborate dishes, recipes were calculated based on their ingredients and proportions using traditional MD recipes; (3) when an FFQ item does not refer to a single food (e.g., blue fish), the intake ratio was calculated based on the data available in a national Spanish survey;[28] (4) the environmental loads of each food were obtained from the meta-analysis[29] published within the recommendations of the EAT-Lancet Commission, and the environmental impact of each food was calculated by multiplying the value of the environmental burden by the daily consumption of each product; and (5) finally, the environmental impact of each participant's diet was calculated as the sum of the individual food contributions, taking into account the information collected in the FFQs.

In addition, to perform these calculations we took into account the following data: burgers and meatballs was considered derived from beef and pork 50% each of them; liver from chicken, beef, and pork 33% each one; sausages, foie gras and other meat products derived from pork; white fish included anglerfish, turbot, sea bass, hake and sole; blue fish included mackerel, salmon, trout, and tuna.

Statistical analysis

Descriptive statistics were used to show the general baseline characteristics of the participants. Means and standard deviations were used to represent dietary intake and environmental impact data. Linear regression models adjusted for sex, age (years), BMI (kg/m^2), and education level (primary, secondary, or university/graduate) were performed to classify participants based on tertiles of adherence to MD, and Kruskal–Wallis tests were used to assess differences between tertiles with respect to 5 environmental indicators (i.e., GHG emissions, land and energy use, acidification and eutrophication). Statistical significance was set at $p < 0.05$.

Stata software version 15.1[30] was used for the statistical analyses, and R software version 4.1.1[31] was used for the determination of the environmental impact of each individual.

Results

The sample included 5800 participants of whom 52% were men, 49% had higher education, 46% were under 65 years of age, and 73% had different degrees of obesity. Higher adherence to MD using the DS Index was significantly associated ($P < 0.05$) with the educational level, age, and BMI (Table 1).

The results obtained in relation to environmental factors according to adherence to MD (based on the DS index tertiles) are shown in Fig. 2. In this model, at baseline, higher adherence to MD (high vs. low) was associated with lower land use (8.94 vs. 10.56 m^2, $P < 0.001$), lower GHG emissions (4895.75 vs. 5133.16 g/CO2-eq, $P < 0.001$), lower energy use (8763.32 vs. 9682.28 kJ, $P < 0.001$), lower acidification (58.98 vs. 69.79 g SO2-eq, $P < 0.001$), and lower eutrophication (22.64 vs. 26.14 g PO4-eq, $P < 0.001$).

Fig. 2 also shows that all environmental indicators decreased after 1 year of intervention. Specifically, a greater adherence to MD (high vs. low) was associated with lower land use (6.81 vs. 8.37 m^2, $P < 0.001$), lower GHG emissions (4513.66 vs. 4776 g/CO2-eq, $P < 0.001$), lower energy use (8004.92 vs. 8817.45 kJ, $P < 0.001$), lower acidification (47.88 vs. 58.12 g SO2-eq, $P < 0.001$), and lower eutrophication (18.13 vs 21.48 g PO4-eq, $P < 0.001$).

Compared to baseline, after one year of the intervention, the average amount of energy consumed by participants decreased (−125.06 Kcal), and the adherence to MD was improved (+0.86) (all $P < 0.001$). As a result of the changes in dietary pattern, the five environmental indicators analysed were significantly reduced from the baseline data to year follow up (GHG emissions: −361.09 g/CO2-eq, acidification: −11.53 g SO2-eq, eutrophication: −4.67 g PO4-eq, energy use: −842.74 kJ and land use: −2.19 m^2) (Table 2).

The main contributor to GHG emissions was meat and fish (38.2% and 26.3% respectively); regarding energy use, the main contributor was meat (57.1%) followed by vegetables (22.3%); and, finally, with respect to acidification, eutrophication and land use, the main contributor was meat (76.9%, 74.6% and 79% respectively) (Fig. 3). After one year of participation in the program, despite decreasing the percentage of contribution to different environmental factors, meat remained the main contributor in GHG emissions (31.7% followed by fish with

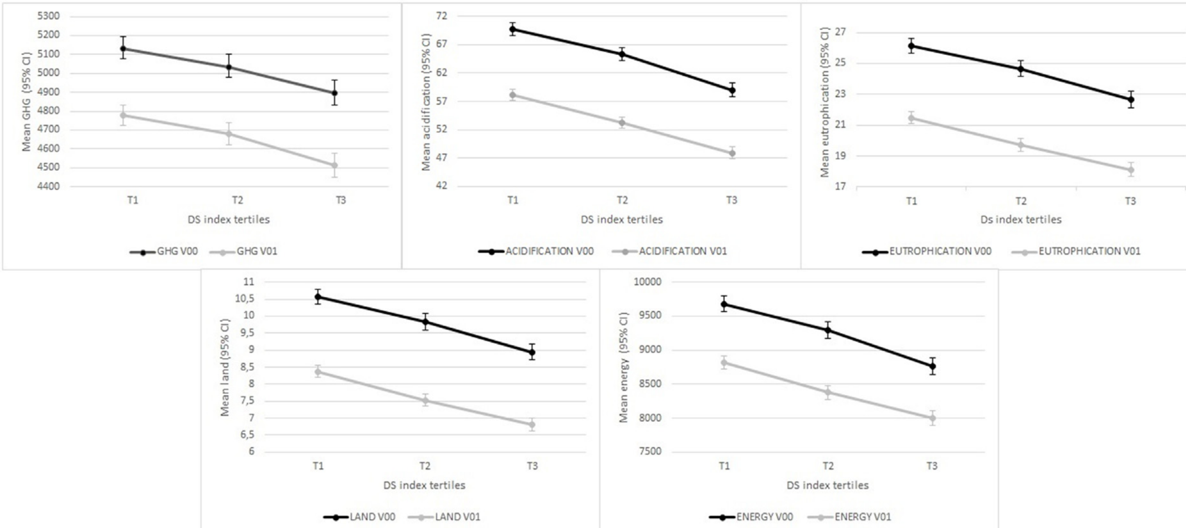

Fig. 2. Environmental footprint for different factors by tertiles of adherence to MD according to the Dietary Score (DS) index. V00 indicates baseline; V01 represents one year of intervention; GHG, Greenhouse gas emissions; and DS, Dietary Score. Linear regression models adjusted for sex, age (years), BMI (kg/m^2) and educational level (primary, secondary or university/graduate) were performed to classify participants based on tertiles of adherence to DS (*All $P < 0.001$).

30.3%), in energy use (52.2% followed by vegetables with 26.6%), in acidification (73.9%), eutrophication (71%) and land use (75.9%) (Fig. 3).

Discussion

The results of this prospective cohort analysis indicated that promoting adherence to a DM pattern was associated with lower environmental impact in terms of GHG emissions, land and energy use, and potential acidification and eutrophication. Additionally, we observed higher adherence to MD classified by tertiles was related with a lower environmental impact. This is consistent with previously published studies, in which high adherence to MD was associated with lower GHG emissions and lower land use.[32–35]

Similarly to our results, the SUN cohort, an observational study conducted in Spain,[36] analysed the actual diet consumed and showed that, in addition to the environmental indicators mentioned above, greater adherence to the MD was related to lower environmental pressure at the level of energy use.

The observation that meat products were associated with a greater environmental impact in all the factors analysed is not surprising, since livestock is directly related to deforestation due to the large amount of agricultural land it uses, and this is related to land degradation and biodiversity loss.[37] These results correspond to different studies, which show that animal products, especially meat, are most responsible for the increase in GHG emissions and increased use of land and energy.[32,33,38,39]

In the present study, after a year of follow-up, although meat remained the main contributor to environmental impact, the percentage of contribution decreased in the five factors analysed. This is consistent with findings from an analysis carried out in a French population in which a 30% reduction in GHG emissions was associated with small changes in diet (replacement of beef by pork).[40] In addition, a Swedish study found that reducing meat consumption by 50% by replacing it with pulses improved the carbon footprint by 20%.[41] Therefore, one option to consider could be dietary advice to reduce and replace meat consumption from different dietary patterns rather than merely suggesting the complete exclusion of these food groups.[42]

We would like to highlight, in our study, after a year of nutritional intervention which promoted following a MD pattern, all environmental indicators decreased, which seems to indicate that MD in addition to being a healthy is a sustainable eating pattern. Although in our work there are two distinct groups (intervention and control), both promote adherence to the MD and for this work we have considered the data together without taking into account the value of the intervention. In our case, we used the Dietary Score (DS) index proposed by Panagiotakos[26] given that the result does not depend on the distribution observed in the study sample but uses independent criteria based on general recommendations.[43]

Table 2
Mean and SD for different factors at baseline and one year of intervention.

	Baseline	1 year	Difference	*p*-value
GHG (g/CO2-eq)	5029.1 ± 1511.9	4668 ± 1293.3	−361.1 ± 1484.4	<0.001*
Acidification (g SO2-eq)	65.1 ± 27	53.5 ± 22.4	−11.5 ± 26.8	<0.001*
Eutrophication (g PO4-eq)	24.6 ± 11.4	19.9 ± 9.4	−4.7 ± 11.3	<0.001*
Energy use (kJ)	9277.8 ± 2723.1	8435 ± 2318.6	−842.7 ± 2722.9	<0.001*
Land use (m^2)	9.8 ± 5.2	7.6 ± 4.2	−2.2 ± 5	<0.001*
DS (points)	33.5 ± 3.9	34.3 ± 3.8	0.9 ± 3.6	<0.001*
Energy intake (Kcal/day)	2368.1 ± 549.5	2243.1 ± 475.6	−125.1 ± 536.7	<0.001*

GHG indicates greenhouse gas emissions; DS, Dietary Score.

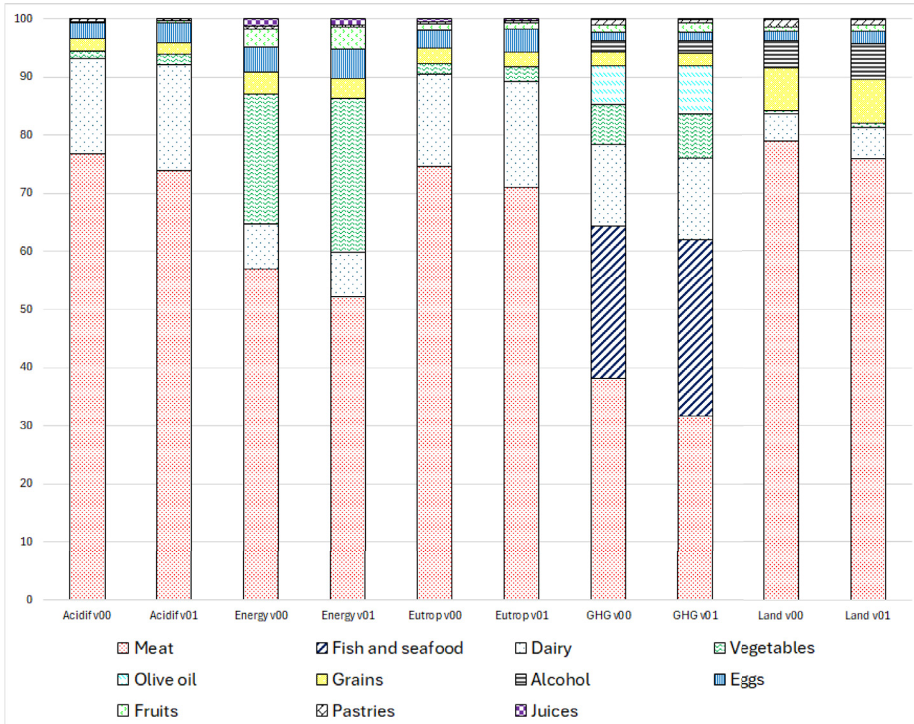

Fig. 3. Contribution of food groups to the different environmental factors analysed at baseline and one year of intervention. V00 indicates baseline; V01, after one year of intervention; Acidif, acidification; Eutrop, eutrophication; GHG, Greenhouse gas emissions; and Land, land use.

In order to calculate the environmental impact of each food, we use data published by Clark et al.[29] that were collected within the Eat-Lancet Commission[27] as, to our knowledge, it is the most comprehensive database currently available to evaluate the five reported environmental factors. This data was based on life cycle assessment (LCA) and included the environmental impacts associated with all relevant activities from pre-farm activities to when a food leaves the farm.

There is currently limited evidence available related to the analysis of the association between dietary interventions and environmental footprint, but our results are partially consistent with those published by Rosi et al.[44] In this article, an intervention to promote adherence to the MD for 10 months, and after adjusting the results for energy, showed a small improvement in environmental sustainability in the selection of menus. On the contrary, in the study carried out by Grasso et al.,[45] after a year of behavioural therapy applying Mediterranean-style dietary guidelines, the authors found no differences in environmental impact. In our case we did not adjust for total energy intake because the intervention is based on the application of a Mediterranean hypocaloric diet and this method, we could camouflage the results obtained.

To date, there is a lack of intervention related evidence. Instead, hypothetical scenarios are analysed in which the environmental impact related to various dietary patterns is assessed, which present support for a shift toward diets with a higher content of plant products and low intake of animal products as having a greater beneficial effect on the environment.[1,46–48]

Evidence assessing the impact of dietary changes on environmental factors has been summarized in a systematic review by Aleksandrowicz et al.,[46] which concluded that switching consumption from Western dietary patterns to more sustainable dietary patterns could reduce up to 70% of land use and GHG emissions. In the same way, in the work published by Belgacem et al.[49] it is stated that this change in the food pattern would mean a saving in land use of 18 m^2/per capita/day, a reduction of 4 kg CO2/per capita/day and a decrease of 16 g PO4 eq/per capita/day.

Current policies for reducing climate change usually focus on the energy sector, while other sectors such as food and livestock do not receive as much attention even though they are responsible for 80% of anthropogenic land use[50] and this, in turn, is a major cause of biodiversity loss. The current system of food production and consumption is considered unsustainable[51] and therefore, in order to guarantee sustainability in the long term, policies that integrate healthy and environmentally friendly dietary recommendations are needed.

From the point of view of the diet–health relationship, it has also been shown that switching to dietary patterns with a lower intake of animal products would be beneficial for both population and environmental health.[52–54] For example, in the study published by Springmann et al.,[53] replacing foods of animal origin with plant-based foods resulted in a reduction of up to 12% in premature mortality. Therefore, the impact MD has both at the health level and the environmental sustainability level is considered, this dietary pattern could be significantly influential in positively addressing the health–diet–environment trilemma.

Limitations

Our study shares some typical limitations of epidemiological studies related to the accuracy of data inferred from indirect methods of reporting food intake, such as FFQs. For this reason, we cannot rule out the existence of recall bias. Nevertheless, the FFQ used is validated in the Spanish adult population showing good validity and reproducibility.[23]

Another related limitation comes from the fact that some of the foods collected in our FFQ questionnaire did not have their environmental impact available in EAT-Lancet. This is the case for some legumes very characteristic of the MD, such as lentils and chickpeas. In addition, this database does not take into account a very important factor for environmental impact and the food system, such as water. Within the MD, characterized by a high consumption of vegetable products, knowing these values could be of help in order to know more accurately the total environmental impact of this dietary pattern.

On the other hand, there is no unified method for calculating the environmental impact of foods, and therefore the data obtained may not be quantitatively comparable with other estimations. Furthermore, we understand that the environmental impact may differ significantly depending on the geographical location, especially in the cultivation of agricultural products, so we always speak of estimates. Finally, the generalizability of the present findings may be limited as they are based on data from an adult population with overweight/obesity with metabolic syndrome.

Strengths

Nonetheless, the present study does have numerous strengths. The large sample size, the multicentre design of the study and the availability of high-quality detailed information obtained by qualified personnel. This provides greater reliability from a nutritional epidemiology point of view. In addition, we have taken into account potential confounding factors that have been included in the statistical models to reduce potential biases.

Another strength is the actual assessment of the change in environmental impact by dietary intervention since most studies are based on hypothetical dietary changes. Moreover, as far we know, this is the first time that GHG emissions have been considered in assessing the environmental impact of the MD, in combination with other indicators, such as land and energy use and the potential for acidification and eutrophication. This allowed us to use the EAT-Lancet commission tables. This database uses life cycle analysis as a technique, which takes into account the entire supply chain from producer to consumer and waste management; it is the most widely used methodology as it unifies the environmental coefficients and allows us comparability between studies. Our findings add new insights on the issue of environmental sustainability and its relationship with food and health.

Conclusions

Participants with higher adherence to the MD pattern had lower environmental impact in the five factors analysed than those with lower adherence. In addition, after a year of dietary intervention following a MD pattern, these five indicators decreased.

Meat products contributed the greater environmental impact across all five dimensions analysed, which suggests that a diet in which there is a lower consumption of this food group may be beneficial in reducing negative dietary-related environmental impact.

Although more studies of this type are needed, it is clear that a shift towards more sustainable dietary patterns such as MD is needed to try to ensure planetary health for future generations.

Author statements

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Ethical approval

The study protocol complied with the ethical standards of the Helsinki Declaration and was approved by the Research Ethics Committees of all recruiting centres.

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Competing interests

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Author contributions

All authors contributed to the study conception, design, and data collection. Material preparation and analysis were performed by L. Álvarez-Álvarez, F. Vitelli-Storelli, M. Rubín-García and V. Martín-Sánchez. The first draft of the manuscript was written by L. Álvarez-Álvarez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Availability of data and material

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval of the PREDIMED-Plus Steering Committee.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2024.02.010.

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