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Effect of a nutritional intervention based on an energy-reduced Mediterranean diet on environmental impact

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Abbreviations: CG, Control group; CO2-eq, Carbon Dioxide equivalents; DS, Diet Score; FFQ, Food frequency questionnaire; GHG, Greenhouse gas; IG, Intervention group; kJ, Kilojoules; MedDiet, Mediterranean Diet; PO4-eq, Phosphate equivalents; SO2-eq, Sulfur Dioxide equivalents.

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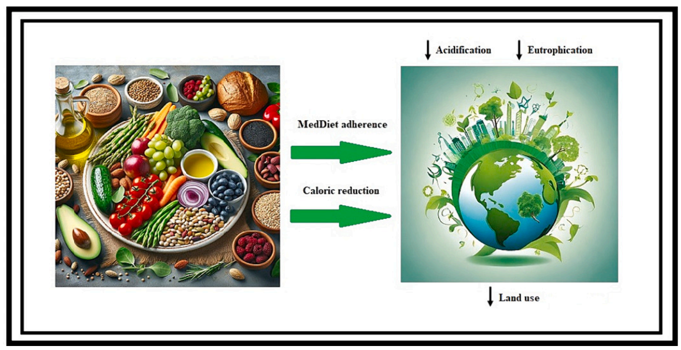
HIGHLIGHTS

- MedDiet adherence and calorie reduction mediate improved environmental impact.
- An energy-reduced MedDiet improves acidification, eutrophication, and land use.
- Meat has a greater impact on acidification, eutrophication, land use and energy.
- In terms of GHGs, the main contributor in the CG was meat and, in the IG, fish.

GRAPHICAL ABSTRACT



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ABSTRACT

Objective: To estimate the environmental impact of a dietary intervention based on an energy-reduced Mediterranean diet (MedDiet) after one year of follow-up.
Methods: Baseline and 1-year follow-up data were used for 5800 participants aged 55–75 years with metabolic syndrome in the PREDIMED-Plus study. Food intake was estimated through a validated semiquantitative food consumption frequency questionnaire, and adherence to the MedDiet was estimated through the Diet Score. Using the EAT-Lancet Commission tables we assessed the influence of dietary intake on environmental impact (through five indicators: greenhouse gas emissions (GHG), land use, energy used, acidification and potential eutrophication). Using multivariable linear regression models, the association between the intervention and changes in each of the environmental factors was assessed. Mediation analyses were carried out to estimate to what extent changes in each of 2 components of the intervention, namely adherence to the MedDiet and caloric reduction, were responsible for the observed reductions in environmental impact.
Results: We observed a significant reduction in the intervention group compared to the control group in acidification levels (−13.3 vs. -9.9 g SO2-eq), eutrophication (−5.4 vs. -4.0 g PO4-eq) and land use (−2.7 vs. -1.8 m2). Adherence to the MedDiet partially mediated the association between intervention and reduction of acidification by 15 %, eutrophication by 10 % and land use by 10 %. Caloric reduction partially mediated the association with the same factors by 55 %, 51 % and 38 % respectively. In addition, adherence to the MedDiet fully mediated the association between intervention and reduction in GHG emissions by 56 % and energy use by 53 %.
Conclusions: A nutritional intervention based on consumption of an energy-reduced MedDiet for one year was associated with an improvement in different environmental quality parameters.

1. Introduction

Climate change is one of the greatest public health threats of our time (Costello et al., 2009; Watts et al., 2015). Negative effects range from rising global temperatures, changes in precipitation patterns, droughts and more intense heat waves (Roca Villanueva et al., 2019) to pathogenic diseases and aggravated transmission pathways (dengue, Zika, malaria or chikungunya among others) (Mora et al., 2022). In addition, it also conditions agricultural and livestock activities, with climate change being associated with a reduction in both the quality and quantity of food produced (Intergovernmental Panel on Climate Change, 2023; Rojas-Downing et al., 2017).

It is estimated that by 2050 the world's population will have increased to almost 10 billion people with the consequent increase in the demand for food that this implies (FAO, 2018). If we take into account that food systems are responsible for approximately 30 % of global greenhouse gas (GHG) emissions (Crippa et al., 2021), 78 % of eutrophication, 32 % of terrestrial acidification (Poore and Nemecek, 2018), 70 % of freshwater use and 60 % of global biodiversity loss (HLPE, 2017), food production becomes a key point to achieve greater environmental sustainability.

According to the latest synthesis report of the Intergovernmental

Panel on Climate Change (IPCC) (Intergovernmental Panel on Climate Change, 2023), one of the measures to mitigate climate change would focus on food systems and within them, one of the key points would be diets (Sun et al., 2022). The Food and Agriculture Organization of the United Nations (FAO) established the definition of sustainable diets as those “with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations” with specific features, such as “protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources” (World Health Organization, 2019).

The choice of different dietary patterns is essential when it comes to making the food system more sustainable since the type of diet that is followed directly influences the quality and quantity of what is eaten and this conditions the individual environmental footprint that is generated (Hess et al., 2016; Willett et al., 2019). Current studies agree that eating patterns with fewer animal foods and more plant foods, in addition to being healthier, have a lower environmental impact (Aleksandrowicz et al., 2016; Chai et al., 2019; Nelson et al., 2016; Willett et al., 2019).

Therefore, the aim of this study was to estimate the reduction of the environmental impact of an intensive nutritional intervention based on an energy-reduced Mediterranean Diet (MedDiet) in a cohort of older Spanish adults with overweight/obesity and Metabolic Syndrome after one year of follow-up in the framework of the PREDIMED-Plus study.

2. Methods

2.1. Study design

This study used baseline and after one year intervention data from the PREDIMED-Plus study. This is a multicentre, randomized (non-blinded) 8-year trial carried out in Spain which objective is to evaluate the effect of an intensive weight loss intervention based on the consumption of an energy-reduced MedDiet, promotion of physical activity and behavioural therapy on the prevention of cardiovascular risk. The study protocol contains all the detailed information (Martínez-González et al., 2019; Salas-Salvadó et al., 2019) and is available on the project 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). The Research Ethics Committees of the 23 recruiting centres approved the study protocol that complied with the ethical standards of the Helsinki Declaration (Cantín, 2014). In addition, all participants gave their written consent to the entry of the program.

2.2. Study population

From September 2013 to November 2016, 23 centres in Spain contacted 9677 people, of which 6874 were included in the program. The participants selected were men (55–75 years) and women (60–75 years) with no history of cardiovascular disease, body mass index $\geq$27 and $<$ 40 kg/m^2, and at least 3 criteria for metabolic syndrome according to the definition of the International Diabetes Federation/National Heart, Lung, and Blood Institute/American Heart Association (Alberti et al., 2009). Participants were randomly assigned in two distinct groups: the intervention group (IG) in which an energy-reduced MedDiet was promoted with physical activity and behavioural therapy guidelines; and the control group (CG) in which general advice about the MedDiet was given but without promoting weight loss. Both groups received 1 l/month of extra virgin olive oil and all participants were encouraged to consume raw nuts.

Our study excluded those participants who had not completed the Food Frequency Questionnaire (FFQ) in one of the two visits and those with extreme energy intake ($<$500 or $>$ 3500 kcal/day in women and $<$ 800 or $>$ 4000 kcal/day in men)(Willett et al., 1997), including finally a sample of 5800 participants (Fig. 1).

2.3. Variables and data collection

At the beginning of the program and at one year of intervention, dietary information was collected through a validated semi-quantitative 143-item (FFQ) for the Spanish population (De La Fuente-Arrillaga et al., 2010; Fernández-Ballart et al., 2010; Martin-moreno et al., 1993). This questionnaire collects information about the previous year's food consumption, with nine possible responses ranging from never or almost never to more than six times a day and with a specific standard portion size for each of the items. The total energy and nutrient consumption of each participant was calculated by multiplying the consumption frequencies by the weight of the standard serving size and the nutritional information was obtained from the Spanish food composition tables (Mataix-Verdú et al., 2013; Moreiras et al., 2018).

To calculate adherence to MedDiet we used the index created by Panagiotakos (Panagiotakos et al., 2007), which uses a score of 0 to 55 points and classifies adherence by tertiles, corresponding the first tertile to a low adherence and the third to the highest adherence. This index considers 11 food groups. Each component has a specific scale, with higher scores for frequent consumption of those foods recommended within the Mediterranean pattern (fruits, vegetables, pulses, potatoes, whole grains, fish, and olive oil) and lower scores for those foods whose consumption should be moderated according to this dietary pattern (poultry, red meat, dairy products with fat, and alcohol). The total score is calculated by adding the points obtained in each component.

Information on socio-demographic variables (age, sex, and educational level) and on lifestyles (dietary habits) was collected at baseline. Anthropometric variables were determined by trained staff according to the PREDIMED-Plus protocol.

2.4. Estimating the environmental footprint

Based on the information collected in the EAT-Lancet Commission tables (Willett et al., 2019) and using the data obtained in the FFQ, we estimated the greenhouse gas (GHG) emissions (grams of CO2-equivalents), land (m^2) and energy use (Kilojoules (kJ)) and potential acidification (grams of SO2-equivalents) and eutrophication (grams of PO4-equivalents) of the diet of each of the study participants, as previously described (Álvarez-Álvarez et al., 2024). It should be noted that the database employed uses life cycle analysis as a technique, taking into account the entire supply chain, from producer to consumer, as well as waste management.

To obtain this data, the following steps were followed:

1) All foods collected in the FFQ for which information was available in the EAT-Lancet Commissions tables were included in the analysis (i.e., 102 items) (Environmental footprint values of each food available in supplementary material);
All foods collected in the FFQ for which information was available in the EAT-Lancet Commissions tables were included in the analysis (i.e., 102 items) (Environmental footprint values of each food available in supplementary material);
2) In the case of items that referred to elaborate dishes, these were estimated taking into account the ingredients that compose them following traditional MedDiet recipes (Flo, 1998; Sánchez-Tainta et al., 2015), and in the case of commercialised processed foods, the nutrition labels of commonly consumed brands were consulted to check the ingredients;
3) When more than one food appeared in a single FFQ item (e.g. white fish, formed by anglerfish, cod, flat fish, sea-bass and turbot), the intake rate was calculated following data from the Spanish national survey (MAPA, 2022);
4) Based on the meta-analysis (Clark and Tilman, 2017) published within the recommendations of the EAT-Lancet Commission, the

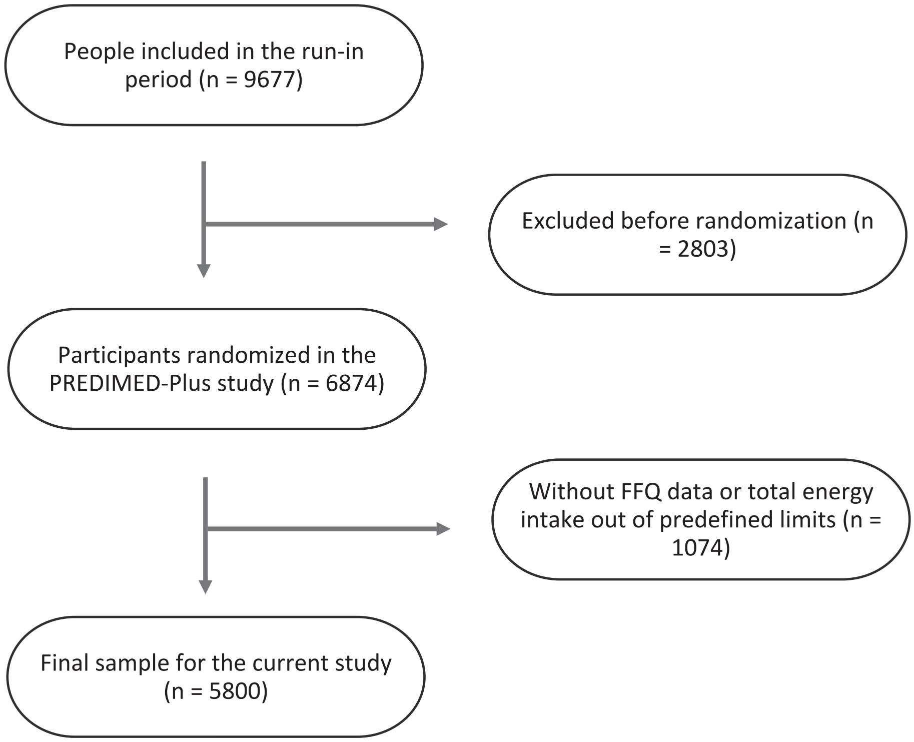

Fig. 1. Flowchart of participants from the PREDIMED-Plus trial.

environmental loads of each food were obtained, and to calculate the environmental impact of each item we multiplied the value of the environmental load by the daily consumption of each one;

5) Finally, the total environmental impact of each participant's diet was obtained by adding the individual food contributions, based on the data obtained in the FFQ.

To carry out these calculations we took into account the following considerations: white fish included anglerfish, hake, seabass, sole and turbot; blue fish included mackerel, salmon, trout, and tuna; burgers and meatballs was considered derived from beef and pork 50 % each of them; liver from chicken, beef, and pork 33 % each one; sausages, pâté and other meat products derived from pork.

2.5. Statistical analysis

Independent mean comparison analyses were performed for baseline and 1-year situations and Kruskal-Wallis tests were used to assess

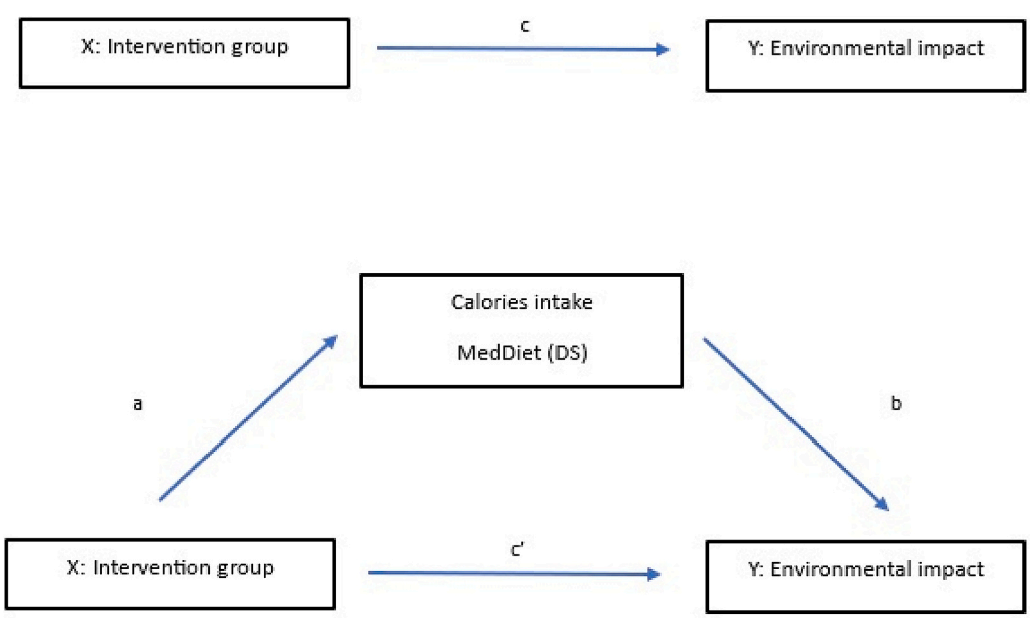

Fig. 2. Conventional mediation model for the association between intervention group and different environmental impact indicators with caloric intake and adherence to the MedDiet as mediators. MedDiet indicates Mediterranean Diet; DS, Dietary Score. c = the total effect of X on Y (c = c' ab); c' = the direct effect of X on Y after controlling for mediators; ab = indirect effect of X on Y.

differences between baseline and follow-up data (paired data) between CG and IG.

To assess whether Mediterranean diet and energy intake were correlated with each other at baseline and in differences at 1 year for GI and CG, Pearson pairwise correlations were performed.

Linear regression models adjusted for sex, age, level of education and baseline caloric intake were used to analyse the association between intervention and reduction of the different environmental pressures analysed. A mediation analysis was conducted using structural equation modelling (Mehmetoglu, 2018). This approach is based on the model proposed by Baron and Kenny (Baron and Kenny, 1986), modified by Iacobucci et al. (Iacobucci et al., 2007) and with an alternative approach proposed by Zhao et al. (Zhao et al., 2010) and was used to determine to what extent MedDiet, caloric reduction and intervention were responsible for reducing the environmental impact assessed through five indicators (Fig. 2). The following steps were carried out:

a) A linear regression that analysed the association between the intervention (independent variable) and the difference in environmental impact (dependent variable), without taking into account the mediators (caloric intake and adherence to the MedDiet) (path c ➔ total effect);
b) A linear regression that analysed the association between the intervention and changes in caloric intake and adherence to the MedDiet (path a);
c) A linear regression that analysed the association between changes in caloric intake and adherence to the MedDiet with the difference in environmental impact (path b);
d) The existence of mediation was determined by analysing the association between the intervention and the difference in environmental impact, while the mediator remains constant (route c’ ➔ direct effect), and the indirect effect (path a x path b).
e) Finally, the proportion mediated by caloric intake and MedDiet adherence was estimated by dividing the indirect effect by the total effect.

Statistical significance was set at $p < 0{,}05$. Stata software version 15.1 (StataCorp LP Statistics/Data Analysis, n.d.) was used for the statistical analysis, and R software version 4.1.1 (R Core Team, 2016) was used for the determination of the environmental impact of each individual.

3. Results

The data obtained on the reduction of the different environmental impact factors analysed in the two groups of the program can be seen in Table 1. It shows how IG reduces the impact on the 5 factors analysed, being the significant difference (IG vs. CG) in the case of acidification (−13.3 vs. -9.9 g SO2-eq), eutrophication (−5.4 vs. -4.0 g PO4-eq), and land use (−2.7 vs. -1.8 m^2). In addition, significant differences were found in the reduction of calories intakes (−178.4 vs. -73.3 kcal) and in the increase in adherence to MedDiet (1.2 vs. 0.5 points).

Mediterranean diet and energy intake were not correlated with each other, neither at baseline ($r = -0.1154$) nor the differences at 1 year for IG ($r = 0.0057$) and CG ($r = -0.0650$).

The main contributor, at the year of participation in the study, in both groups (IG vs. CG) was meat with respect to acidification (72.9 vs. 74.8 %), eutrophication (69.6 vs. 72.2 %), energy (50.9 vs. 53.5 %) and land use (75.3 vs. 76.4 %); the main contributor to GHG emissions for CG was meat (33.5 %) and in IG were fish and seafood (32.1 %) (Fig. 3).

In addition, Fig. 4 shows the changes that occur in the percentage of contribution of the different food groups in the different factors analysed after one year of inclusion in the program. The IG increases the % contribution against the CG (IG vs. CG) in dairy products, fruits, vegetables, and eggs in the five factors analysed; in addition, it increases the % of fish and shellfish in the case of GHG emissions (5.6 vs. 2.7 %) and alcohol in the case of land use (1.7 % vs. 1.3 %). On the other hand, the IG decreases the % of contribution against the CG in meat, juices, cereals, and pastries in the five environmental indicators.

Regarding the mediation analysis (Fig. 5), there was a significant association between the IG and caloric reduction and the IG and adherence to the MedDiet (β: −104.7 and 0.68 respectively, path a) and between each of these mediators and the change in environmental indicators (path b): GHG (β: 1.39 and − 25.79, respectively), acidification (β: 0.02 and − 0.91, respectively), eutrophication (β: 0.01 and − 0.27, respectively), land use (β: 0.003 and − 0.13, respectively) and energy use (β: 2.7 and − 103.11, respectively).

The direct and indirect effects of the intervention on changes in different indicators of environmental sustainability with adherence to the MedDiet and caloric reduction as mediators are shown in Table 2. Caloric reduction significantly mediated the association between intervention and reduction of acidification, eutrophication, and land use, explaining 55 %, 51 % and 38 % of the overall association respectively. It also significantly mediated the association between the intervention and increased GHG and energy use, but as the direction of direct effect and indirect effect were opposite the proportion of mediation may not be interpretable (Valeri and VanderWeele, 2013).

On the other hand, adherence to the MedDiet significantly mediated the association between the intervention and reduction of acidification, eutrophication, and land use, explaining 15 %, 10 % and 10 % of the overall association respectively. In addition, adherence to MedDiet fully mediated the association between intervention and reduction of GHG emissions by 56 % and energy use by 53 %.

Path a indicates the regression coefficient for the association

Table 1
Caloric intake, adherence to the MedDiet and environmental impact for the different study groups.

	Baseline			1 year intervention			Differences		
	CG	IG		CG	IG		CG	IG	
	Mean (SD)	Mean (SD)	*p*-value	Mean (SD)	Mean (SD)	*p*-value	Mean (SD)	Mean (SD)	*p*-value
Caloric intake (Kcal/day)	2374.5 (553.2)	2361.5 (545.7)	0.368	2300.8 (490.3)	2183.1 (452.2)	<0.001	−73.7 (525.6)	−178.4 (543.0)	**<0.001**
Dietary Score (points)	33.4 (4.0)	33.5 (3.9)	0.196	33.9 (3.8)	34.7 (3.7)	<0.001	0.5 (3.5)	1.2 (3.7)	**<0.001**
GHG (g/CO2-eq)	5058.9 (1529.8)	4998.1 (1492.7)	0.126	4713.8 (1324.6)	4620.4 (1258.4)	0.006	−345.1 (1460.0)	−377.7 (1509.4)	0.403
Acidification (g SO2-eq)	61.7 (27.6)	64.4 (26.3)	0.053	55.8 (23.2)	51.1 (21.2)	<0.001	−9.9 (26.5)	−13.3 (27.1)	**<0.001**
Eutrophication (g PO4-eq)	24.9 (11.7)	24.3 (11.1)	0.047	20.9 (9.9)	18.9 (8.9)	<0.001	−4.0 (11.2)	−5.4 (11.5)	**<0.001**
Land use (m^2)	9.9 (5.2)	9.8 (5.2)	0.338	8.2 (4.3)	7.1 (3.9)	<0.001	−1.8 (4.9)	−2.7 (5.1)	**<0.001**
Energy use (kJ)	9307.2 (2745)	9247.2 (2700.3)	0.402	8519.3 (2362.9)	8347 (2268.7)	0.005	−787.9 (2647.2)	−899.7 (2798.8)	0.119

Notes: Mean and SD for different factors at baseline and one year of intervention for both study groups. CG indicates control group; IG, intervention group; SD, standard deviation; GHG, greenhouse gas emissions. The results highlighted in bold are those statistically significant ($p < 0.05$).

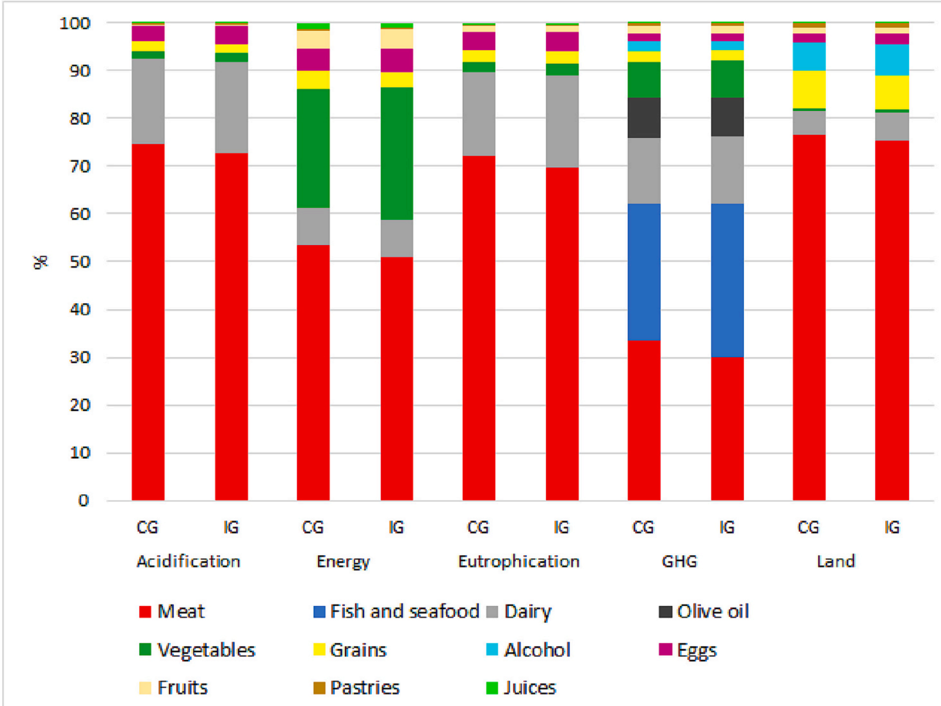

Fig. 3. Contribution of food groups to the different environmental factors analysed at one year of intervention.
*CG indicates control group; IG, intervention group; Eutrop, eutrophication; GHG, Greenhouse Gas emissions; and Land, land use.

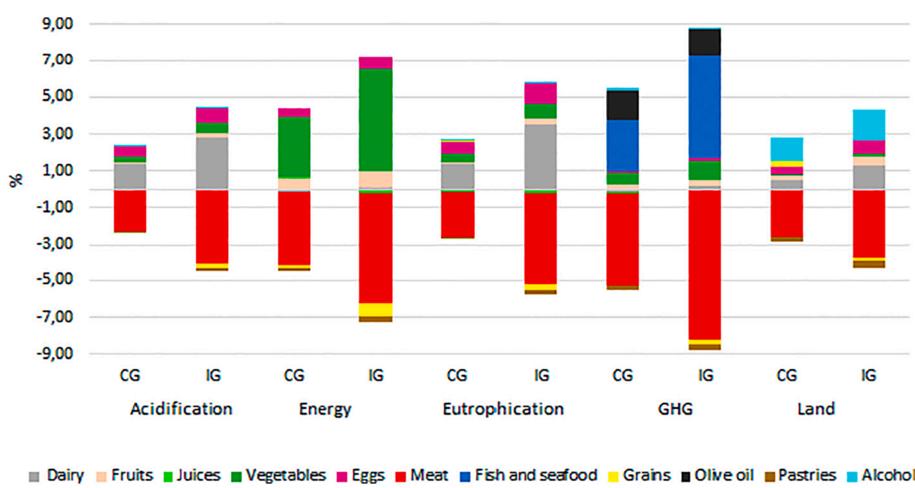

Fig. 4. Change in percentage of contribution of food groups to the different environmental factors analysed at one year of intervention.
*CG indicates control group; IG, intervention group; GHG, Greenhouse Gas emissions; and Land, land use.

between intervention and caloric intake and adherence to the MedDiet. Path b indicates the regression coefficient for the association between caloric intake and adherence to the MedDiet with the different indicators of environmental sustainability. Path c' indicates the direct effect of the intervention on environmental sustainability indicators after adjustment for caloric intake or adherence to the MedDiet. Path c indicates the simple total effect of the intervention on environmental sustainability indicators without adjustment for caloric intake and adherence to the MedDiet.

4. Discussion

This work shows how a nutritional intervention based on a one-year energy-reduced MedDiet improves environmental impact data, doing so significantly in the case of acidification, eutrophication, and land use. In addition, it shows how this improvement in environmental sustainability is mediated by adherence to MedDiet and caloric reduction.

To our knowledge, the present study is the first to evaluate the role of caloric reduction and adherence to the MedDiet in the relationship between intensive nutritional intervention and environmental impact reduction by using a mediation analysis. In our work, the reduction in caloric intake acted as a mediator between nutritional intervention and the reduction in acidification, eutrophication, and land use (with a mediated proportion of 55 %, 51 % and 38 % respectively). In the same way, but to a lesser extent, greater adherence to the MedDiet acted as a partial mediator of these associations (with a mediated proportion of 15 %, 10 % and 10 % respectively).

The food group that had the most environmental impact on both

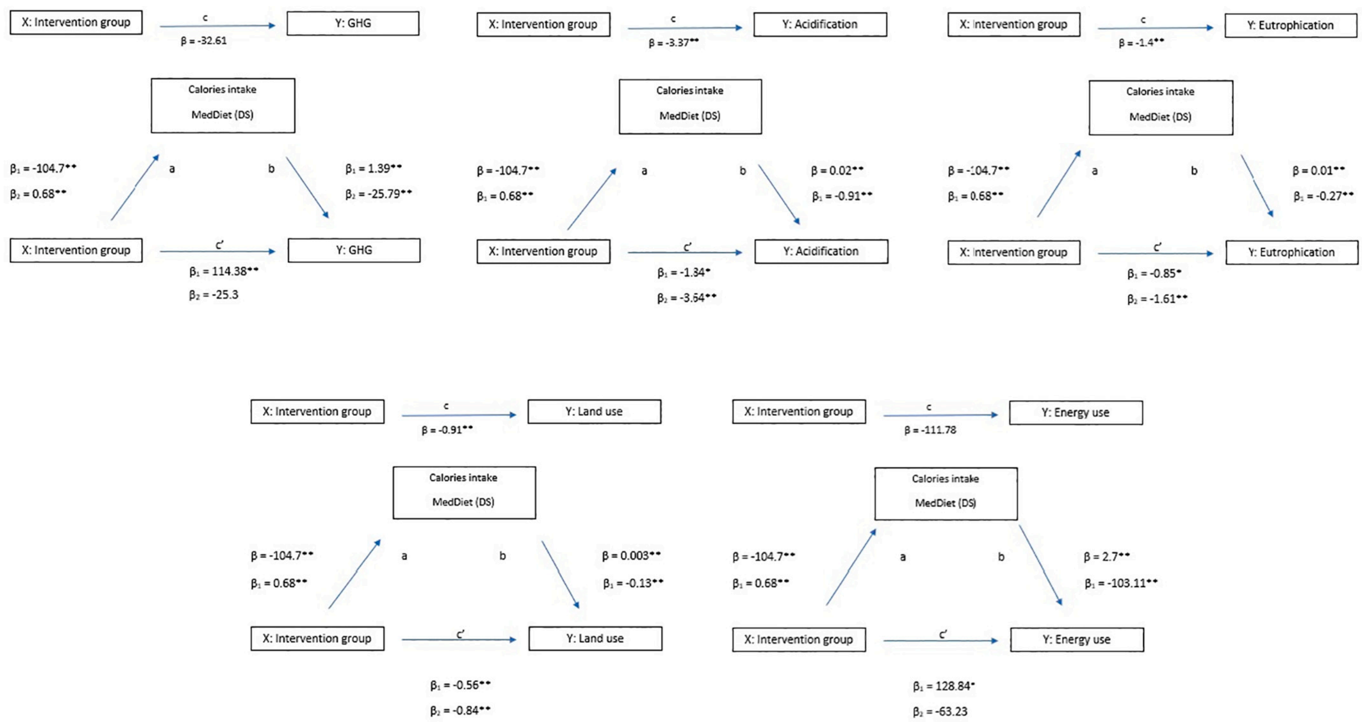

Fig. 5. Conventional mediation scheme for the association between the intervention and the different indicators of environmental sustainability with caloric intake and adherence to MedDiet as mediators. Mediation model adjusted for sex, age, education level and baseline caloric intake.
* $p < 0.05$; ** $p < 0.001$.

Table 2
Direct and indirect effects of the intervention on different indicators of environmental sustainability with caloric intake and adherence to the MedDiet as mediators.

Independent variable	Mediator	Outcome variable	Indirect effect	Direct effect	Proportion Mediated
			β Coefficient (95 % CI)	β Coefficient (95 % CI)	%
Intervention group	Energy intake	GHG	−145.6 (−184.7 to −106.5)*	114.4 (47.5 to 181.3)*	non interpretable
		Acidification	−2.3 (−2.9 to −1.7)*	−1.8 (−2.8 to −0.9)*	55 % partial
		Eutrophication	−0.9 (−1.1 to −0.6)*	−0.9 (−1.3 to −0.5)*	51 % partial
		Land use	−0.3 (−0.4 to −0.3)*	−0.6 (−0.8 to −0.3)*	38 % partial
		Energy use	−242.7 (−308.3 to −177.1)*	128.8 (4.7 to 253.0)*	non interpretable
Intervention group	Mediterranean Diet	GHG	−17.0 (−25.6 to −8.5)*	−13.5 (−90.0 to 63.0)	56 % complete
		Acidification	−0.6 (−0.8 to −0.4)*	−3.6 (−4.7 to −2.6)*	15 % partial
		Eutrophication	−0.2 (−0.2 to −0.1)*	−1.6 (−2.0 to −1.2)*	10 % partial
		Land use	−0.1 (−0.1 to −0.06)*	−0.8 (−1.1 to −0.6)*	10 % partial
		Energy use	−70.3 (−93.2 to −47.5)*	−63.2 (−195.1 to 68.6)	53 % complete

Mediation model adjusted for sex, age, education level and starting point of caloric intake. Notes: GHG indicates greenhouse gas emissions; CI, confidence interval.
[*] Indicates $p < 0.05$.

groups (CG and IG) in the 5 indicators analysed were meat products, with the greatest impact always on the CG, except only the IG in which the largest contributor to the GHG emission was fish. This is in line with different published works that establish that animal products, and more specifically meat, are responsible for the emission of a greater amount of GHG and a greater use of energy and land (Hedenus et al., 2014; Hjorth et al., 2020; Tepper et al., 2022; Tilman and Clark, 2014; van de Kamp et al., 2018). This could be explained by the fact that about 70 % of global agricultural land is used by livestock, which translates into the main cause of deforestation and, in turn, leads to further land degradation (Friel et al., 2009; Stehfest et al., 2009).

In the case of the IG, the largest contributor to GHG emissions was fish, increasing its consumption after a year of intervention. This may be the reason why although the IG reduces GHG emissions more than the CG, it does not do so significantly. Although within the MedDiet pattern the consumption of 2 to 3 servings per week of fish is recommended for its indisputable health benefits (Chen et al., 2022; Jurek et al., 2022; Mohan et al., 2021), fish may contribute to exposure to certain pollutants such as heavy metals (Castaño et al., 2015) and, in addition, has GHG values similar to meat, so this recommendation may not be as sustainable (Lofstedt et al., 2021).

Despite the fact that there is increasing evidence of the relationship between dietary habits and the impact on the environment (Stehfest et al., 2009; Tilman and Clark, 2014; Tukker and Jansen, 2006), one of the problems that we find when comparing our results is that there are few published papers analysing the real change in environmental impact through dietary interventions. Nevertheless, our results are in line with those published by Rosi et al. (Rosi et al., 2022), whose study showed a certain improvement in environmental sustainability promoting adherence to the MedDiet. In addition, they are in line with other papers already published in which authors observed a reduction in GHG emissions and in the use of land and energy with a high adherence to the MedDiet (Baudry et al., 2023; Fresán et al., 2018; García et al., 2023; Germani et al., 2014; Grosso et al., 2020; Tepper et al., 2022).

Most of the studies are based on hypothetical changes in the consumption of certain populations, but agree that the consumption of diets rich in plant products and with a lower contribution of animal products would have a clear benefit on environmental sustainability (Aleksandrowicz et al., 2016; Belgacem et al., 2021; Serra-Majem et al., 2018). For example, the review published by Fresán et al. (Fresán and Sabaté, 2019) exposed that the shift from omnivorous diets to vegan and ovo-lactovegetarian options is associated with the use of fewer natural resources and lower GHG emissions and therefore with greater environmental sustainability, and the review published by Berardy et al. (Berardy et al., 2022) linked the use of vegetable drinks with a more sustainable diet. However, it should be mentioned that vegetarian diets, if not properly planned, can lead to deficiencies in certain micronutrients such as vitamin D, vitamin B12, calcium or iron (Castañé and Antón, 2017; Key et al., 2006).

Compared to the large number of studies analysing the relationship between diet and health, there is very little literature (although it is increasing considerably in recent years) that addresses the relationship between dietary patterns and environmental sustainability. It is well known that dietary choices affect people's health, and also that those dietary choices, along with the food system, affect the environment. Therefore, in recent years the use of the term "trilemma diet-environment-health" has spread.

In this context, the MedDiet, characterised by moderation and frugality, is postulated as a reference dietary standard since, in addition to its known benefits on cardiovascular health, the prevention of chronic diseases and certain types of cancer (Álvarez-Álvarez et al., 2019; Álvarez-álvarez et al., 2021; Guasch-Ferré and Willett, 2021; Martinez-Gonzalez and Bes-Rastrollo, 2014; Rosato et al., 2019; Salas-Salvado et al., 2011; Schwingshackl et al., 2017), it is a dietary model that promotes biodiversity and reduces environmental impact (Germani et al., 2014; Serra-Majem and Ortiz-Andrellucchi, 2018).

5. Strengths and limitations

One of the main limitations of our work is that there is not a single database that gathers the environmental impact generated by food, but rather there are numerous databases collecting information, so the results obtained may not be quantitatively comparable. In addition, we understand that there are products that could be produced locally and therefore have a different environmental impact than the one used for our calculations. It should also be taken into account that the environmental impact may vary depending on the geographical location, especially in the cultivation of agricultural products, so we always talk about estimates.

Another of the limitations is that the database on which we rely to perform the calculations does not include all the items of the FFQ, so they were outside the analysis food with great presence in the MedDiet as some types of legumes and nuts. Also, recall bias cannot be excluded when food intake data are obtained from an indirect reporting method such as the FFQ. However, this FFQ has been validated in the Spanish population and shows a good level of reproducibility and validity (De La Fuente-Arrillaga et al., 2010). In addition, the population on which the study was based was adults aged 55–75 years with metabolic syndrome, which may limit the extrapolation of the results to general populations.

Finally, although a dietary intervention is not carried out on the CG or an energy-reduced diet is applied, it is given MedDiet guidelines that may have prevented seeing more differences between both groups since both decrease caloric intake and improve adherence to the MedDiet after one year of permanence in the study.

As far as we know, there is no published study examining the relationship between an intensive nutritional intervention based on an energy-reduced MedDiet and the reduction of environmental impact using mediation analysis. Therefore, we believe that this work can fill this gap in literature.

Another of the strengths of this work is that it performs an analysis of the real change in the environmental impact by nutritional intervention while most of the published studies are based on hypothetical scenarios of change in dietary patterns.

In addition, although normally this type of studies focuses on GHG emissions, this work has taken into account four other indicators to assess the environmental impact of the MedDiet: acidification, eutrophication and land and energy use.

Finally, it is also necessary to mention the size of the sample used to carry out the analysis that is relatively large and that the database employed uses life cycle analysis as a technique.

6. Conclusions

After a year of intensive nutritional intervention with promotion of energy-reduced MedDiet, IG participants reduced to a greater extent than CG the five environmental impact indicators analysed, making it significantly in acidification, eutrophication, and land use.

Although in almost all cases, meat products were the ones that contributed the most to the environmental impact in all the indicators analysed, the IG always had a lower consumption, which strengthens the idea that diets with less contribution of these products will have a lower environmental impact.

In addition, this study shows how this improvement in environmental impact was mediated in part by the increase in adherence to MedDiet and the caloric reduction in the diet of the participants.

Therefore, an intensive nutritional intervention based on the consumption of an energy-reduced MedDiet is associated with the improvement of different environmental quality parameters which translates into a more sustainable diet.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2024.172610.

Ethics approval and consent to participate

The study protocol 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.

Consent for publication

Informed consent was obtained from all subjects involved in the study.

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Declaration of competing interest

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Data availability

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. There are restrictions on the availability of data for the PREDIMED-Plus trial, due to the signed consent agreements around data sharing, which only allow access to external researchers for studies following the project purposes. Requestors wishing to access the PREDIMED-Plus trial data used in this study can make a request to the PREDIMED-Plus trial Steering Committee chair: jordi.salas@urv.cat. The request will then be passed to members of the PREDIMED-Plus Steering Committee for deliberation.

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