



Ultra-processed foods consumption as a promoting factor of greenhouse gas emissions, water, energy, and land use: A longitudinal assessment



Silvia García^{a,b,c}, Rosario Pastor^{b,d}, Margalida Monserrat-Mesquida^{a,b,c}, Laura Álvarez-Álvarez^{e,f}, María Rubín-García^{e,f}, Miguel Ángel Martínez-González^{a,g}, Jordi Salas-Salvadó^{a,h,i}, Dolores Corella^{a,j}, Montserrat Fitó^{a,k}, J. Alfredo Martínez^{a,l,m}, Lucas Tojal-Sierra^{a,n}, Julia Wärnberg^{a,o}, Jesús Vioque^{e,p}, Dora Romaguera^{a,c}, José López-Miranda^{a,q}, Ramon Estruch^{a,r}, Francisco J. Tinahones^{a,s}, José Manuel Santos-Lozano^{a,t}, Lluís Serra-Majem^{a,u}, Naomi Cano-Ibañez^{e,v}, Xavier Pintó^{a,w}, Miguel Delgado-Rodríguez^{n,x}, Pilar Matía-Martín^y, Josep Vidal^{z,aa}, Clotilde Vázquez^{ab}, Lidia Daimiel^{a,ac,ad}, Emili Ros^{a,ae}, Pilar Buil-Cosiales^{ag}, María Ángeles Martínez-Rodríguez^{a,h,i}, Oscar Coltell^{aj,af}, Olga Castañer^{a,k}, Antonio García-Ríos^{a,q}, Concepción Barceló^{ag}, Enrique Gómez-Gracia^{a,ah}, María Ángeles Zulet^{a,m}, Jadwiga Konieczna^{a,c}, Rosa Casas^{a,r}, Paloma Massó-Guijarro^{v,ai,aj}, Leire Goicolea-Güemez^{a,n}, María Rosa Bernal-López^{a,s}, Maira Bes-Rastrollo^{ag}, Sangeetha Shyam^{a,h,i}, José I. González^{aj}, María Dolores Zomeño^{a,h,i}, Patricia J. Peña-Orihuela^{a,q}, Sandra González-Palacios^{e,p}, Estefanía Toledo^{ag}, Nadine Khoury^{a,h,i}, Karla Alejandra Perez^{a,k}, Vicente Martín-Sánchez^{e,f}, Josep A. Tur^{a,b,c,*}, Cristina Bouzas^{a,b,c}

^a CIBER Fisiopatología de la Obesidad y Nutrición (CIBEROBN), Instituto de Salud Carlos III (ISCIII), 28029 Madrid, Spain

^b Research Group on Community Nutrition & Oxidative Stress, University of Balearic Islands-IUNICS, 07122 Palma de Mallorca, Spain

^c Health Research Institute of the Balearic Islands (IdISBa), 07120 Palma de Mallorca, Spain

^d Faculty of Health Sciences, Catholic University of Avila, 05005 Avila, Spain

^e CIBER de Epidemiología y Salud Pública (CIBERESP), Instituto de Salud Carlos III, 28029 Madrid, Spain

^f Research Group on Interactions Gene-Environment and Health (GIIGAS), Institute of Biomedicine (IBIOMED), University of León, 24071 León, Spain

^g University of Navarra, Department of Preventive Medicine and Public Health, IDISNA, Pamplona, Spain

^h Universitat Rovira i Virgili, Departament de Bioquímica i Biotecnologia, Unitat de Nutrició, 43201 Reus, Spain

ⁱ Institut d'Investigació Sanitària Pere Virgili (IISPV), 43201 Reus, Spain

^j Department of Preventive Medicine, University of Valencia, 46100, Valencia, Spain

^k Unit of Cardiovascular Risk and Nutrition, Institut Hospital del Mar de Investigaciones Médicas Municipal d'Investigació Mèdica (IMIM), 08003 Barcelona, Spain

^l Precision Nutrition and Cardiometabolic Health Program, IMDEA Food, CEI UAM + CSIC, 28049 Madrid, Spain

^m Department of Nutrition, Food Sciences, and Physiology, Center for Nutrition Research, University of Navarra, 31008 Pamplona, Spain

ⁿ Bioaraba Health Research Institute, Cardiovascular, Respiratory and Metabolic Area, Osakidetza Basque Health Service, Araba University Hospital, University of the Basque Country UPV/EHU, 48013 Vitoria-Gasteiz, Spain

^o Department of Nursing, University of Málaga, Institute of Biomedical Research in Málaga (IBIMA), 29071 Málaga, Spain

^p Instituto de Investigación Sanitaria y Biomédica de Alicante, Universidad Miguel Hernández (ISABIAL-UMH), 03550 Alicante, Spain

^q Department of Internal Medicine, Maimonides Biomedical Research Institute of Cordoba (IMIBIC), Reina Sofía University Hospital, University of Cordoba, 14004 Cordoba, Spain

^r Department of Internal Medicine, Institut d'Investigacions Biomèdiques August Pi Sunyer (IDIBAPS), Hospital Clínic, University of Barcelona, 09036 Barcelona, Spain

^s Virgen de la Victoria Hospital, Department of Endocrinology, Instituto de Investigación Biomédica de Málaga (IBIMA), University of Málaga, 29010 Málaga, Spain

^t Department of Family Medicine, Research Unit, Distrito Sanitario Atención Primaria Sevilla, 41013 Sevilla, Spain

^u Research Institute of Biomedical and Health Sciences (UIBS), University of Las Palmas de Gran Canaria & Centro Hospitalario Universitario Insular Materno Infantil (CHUIMI), Canarian Health Service, 35016 Las Palmas de Gran Canaria, Spain

^v Department of Preventive Medicine and Public Health, University of Granada, 18016 Granada, Spain

^w Lipids and Vascular Risk Unit, Internal Medicine, Hospital Universitario de Bellvitge-IDIBELL, Hospitalet de Llobregat, 08907 Barcelona, Spain

^x Division of Preventive Medicine, Faculty of Medicine, University of Jaén, 23071 Jaén, Spain

^y Department of Endocrinology and Nutrition, Instituto de Investigación Sanitaria Hospital Clínico San Carlos (IdISSC), 28040 Madrid, Spain

^z CIBER Diabetes y Enfermedades Metabólicas (CIBERDEM), Instituto de Salud Carlos III (ISCIII), 28029 Madrid, Spain

^{aa} Department of Endocrinology, Institut d' Investigacions Biomèdiques August Pi Sunyer (IDIBAPS), Hospital Clínic, University of Barcelona, 08036 Barcelona, Spain

^{ab} Department of Endocrinology and Nutrition, Hospital Fundación Jiménez Díaz, Instituto de Investigaciones Biomédicas IISFJD, University Autònoma, 28040 Madrid, Spain

Abbreviations: UPF, Ultra-processed Foods; Mets, Metabolic Syndrome; MedDiet, The Mediterranean Diet; LCA, Life Cycle Assessment; GHGs, Greenhouse gas emissions; BMI, Body mass index; FFQ, Food frequency questionnaire; PA, Physical activity; CO₂eq, Carbon Dioxide equivalent; m³, Cubic meters; MJ, Megajoules; Pt, points of land use; T1, Tertile 1; T2, Tertile 2; T3, Tertile 3; SD, Standard deviation; GLM, General Linear Model; METs, Metabolic equivalents of task; FAO, Food and Agriculture Organization.

* Corresponding author at: Research Group on Community Nutrition and Oxidative Stress, University of the Balearic Islands-IUNICS, IDISBA & CIBEROBN, Guillem Colom Bldg, Campus, E-07122 Palma de Mallorca, Spain.

E-mail address: pep.tur@uib.es (J.A. Tur).

<http://dx.doi.org/10.1016/j.scitotenv.2023.164417>

Received 21 March 2023; Received in revised form 15 May 2023; Accepted 21 May 2023

Available online 24 May 2023

0048-9697/© 2023 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC license (<http://creativecommons.org/licenses/by-nc/4.0/>).

^{ac} Nutritional Control of the Epigenome Group, Precision Nutrition and Obesity Program, IMDEA Food, CEI UAM + CSIC, 28049 Madrid, Spain

^{ad} Departamento de Ciencias Farmacéuticas y de la Salud, Facultad de Farmacia, Universidad San Pablo-CEU, CEU Universities, Urbanización Montepríncipe, 28660 Boadilla del Monte, Spain

^{ae} Lipid Clinic, Department of Endocrinology and Nutrition, Institut d'Investigacions Biomèdiques August Pi Sunyer (IDIBAPS), Hospital Clínic, 08036 Barcelona, Spain

^{af} Department of Computer Languages and Systems, University Jaume I, 12071 Castellón, Spain

^{ag} Centro Salud Cabo Huertas, 03540 Alicante, Spain

^{ah} Department of Public Health and Psychiatry, School of Medicine, University of Malaga, and Biomedical Research Institute of Malaga (IBIMA), 29010 Málaga, Spain

^{ai} Preventive Medicine Unit, University Hospital Virgen de las Nieves, 18014 Granada, Spain

^{aj} Instituto de Investigación Biosanitaria de Granada (IBS.GRANADA), 18012 Granada, Spain

^{ak} Blanquerna-Ramon Llull University, 08022, Barcelona, Spain

HIGHLIGHTS

- Decreasing consumption of ultra-processed foods may improve environmental sustainability.
- The lower ultra-processed food dietary contents, the lower the environmental footprints of the diet consumed.
- Decreasing ultra-processed food consumption should be considered for health and for environmental protection.

GRAPHICAL ABSTRACT

Food intake, ultra-processed foods consumption, and environmental indicators (gas emissions, water, energy and land use) were assessed in 55-75-year-old participants (n=5879)



Low consumption of ultraprocessed foods may contribute to environmental sustainability

ARTICLE INFO

Editor: Jay Gan

Keywords:

Ultra-processed foods
Greenhouse gas emissions
Energy use
Land use
Water use
Health
Diet

ABSTRACT

Background: Dietary patterns can produce an environmental impact. Changes in people's diet, such as the increased consumption of ultra-processed food (UPF) can not only influence human health but also environment sustainability. **Objectives:** Assessment of the impact of 2-year changes in UPF consumption on greenhouse gas emissions and water, energy and land use.

Design: A 2-year longitudinal study after a dietary intervention including 5879 participants from a Southern European population between the ages of 55–75 years with metabolic syndrome.

Methods: Food intake was assessed using a validated 143-item food frequency questionnaire, which allowed classifying foods according to the NOVA system. In addition, sociodemographic data, Mediterranean diet adherence, and physical activity were obtained from validated questionnaires. Greenhouse gas emissions, water, energy and land use were calculated by means of the Agribalyse® 3.0.1 database of environmental impact indicators for food items. Changes in UPF consumption during a 2-year period were analyzed. Statistical analyses were conducted using computed General Linear Models.

Results: Participants with major reductions in their UPF consumption reduced their impact by -0.6 kg of CO₂e and -5.3 MJ of energy. Water use was the only factor that increased as the percentage of UPF was reduced.

Conclusions: Low consumption of ultra-processed foods may contribute to environmental sustainability. The processing level of the consumed food should be considered not only for nutritional advice on health but also for environmental protection.

Trial registration: ISRCTN, ISRCTN89898870. Registered 05 September 2013, <http://www.isrctn.com/ISRCTN89898870>.

1. Introduction

Ultra-processed foods (UPF) are defined as industrial products produced from substances obtained from food or synthesized from other organic sources. They usually contain little or none of the primary food, are ready to eat or heat, and are high in additives, including fat, salt, or sugar (Talens et al., 2020). Different factors such as eating in fast-food restaurants (Souza et al., 2021), economic and social development of a region, food system industrialization, technological change and globalization may be also affecting the increase of UPF consumption and deteriorating the diet both in developed and developing countries (Baker et al., 2020; Monteiro et al., 2013).

Higher consumption of UPF could have harmful effects a population's health, increasing the risk of overweight and obesity, cardiovascular diseases, type 2-diabetes, cancer, metabolic syndrome (MetS) and other non-communicable diseases (Talens et al., 2020; Poti et al., 2017). Further evidence is required to understand the mechanisms by which UPFs impact health, beyond nutrient-based interactions (Poti et al., 2017).

Changing the diet to a less processed one could be helpful for health but also for environmental sustainability. UPF are unnecessary foods that should not be present in a balanced diet, and promote overconsumption, which is one of the main reasons for the increasing negative environmental impact (Anastasiou et al., 2022a; Anastasiou et al., 2022b). UPF production is also a primary driver off environmental pressures (Anastasiou et al., 2022a; Anastasiou et al., 2022b; da Silva et al., 2021; Garzillo et al., 2022; Kesse-Guyot et al., 2023). Each life cycle assessment (LCA) stage of UPF production contributes in a different way to the negative environmental impact, which is characterized by extensive monoculture crops, high energy demands for processing, a long transport chain and excessive packaging (Anastasiou et al., 2022b). One study found that the final LCA stages such creating the final product and packaging were the greatest environmental impact contributors in UPF-rich diets (Kesse-Guyot et al., 2023). Climate change, air pollution, biodiversity loss, land use, energy use, water use, and food wastage are the environmental parameters used to measure UPF's sustainability, they are all interconnected and negatively affected by the ultra-processed food system (Anastasiou et al., 2022a;

Anastasiou et al., 2022b). Land use, water use, and greenhouse gas emissions (GHGs) are the largest contributors to the UPF environmental impact. Additionally, meat-based UPF products also have greater negative impacts compared to plant-based options in the case of land use (Anastasiou et al., 2022a).

The Mediterranean Diet (MedDiet) is a healthy dietary pattern, based on a high consumption of fresh fruits and vegetables, unrefined cereals, and a reduced quantity of animal products consumed, mainly red and processed meat (Macdiarmid, 2013; Serra-Majem et al., 2020), which in turn leads to a reduced environmental footprint (García et al., 2023). Food based dietary guidelines (FBDG) are including sustainable diets in their recommendations (Monteiro et al., 2015; Tapsell et al., 2016; The Nutrition Division, 2019), and the environmental consequences of food systems is a consideration in public health agendas (United Nations (UN), n.d.; Willett et al., 2019). It is worth noting that the 2015 Dietary Guidelines for the Brazilian Population (Ministry of Health of Brazil, 2015) and the 2022 Dietary Guidelines for Chile (Ministerio de Salud, Subsecretaría de Salud Pública, División de Políticas Públicas Saludables y Promoción, Departamento de Nutrición y Alimentos, 2022) specifically discuss UPFs environmental impact. However, integrating sustainability in FBDG is still a fragmented process; guidelines and a guidance for stakeholders are necessary to adequately integrate sustainability into FBDG (Mazac et al., 2021).

UPF consumption has negative health impacts, and its environmental impact must also be considered. This study aims to assess how a 2-year change in UPF consumption affects the environmental impacts of the diet.

2. Methods

2.1. Design

This study is a longitudinal, multicenter, parallel-group, randomized trial conducted on the Spanish population. The study protocol can be found elsewhere (Martínez-González et al., 2019). The trial was registered in 09/05/2013 at the International Standard Randomized Controlled Trial (ISRCT; <http://www.isrctn.com/ISRCTN89898870>) with number 89898870.

2.2. Participants, recruitment, and ethics

Fig. 1 shows the eligible participants flow-chart; 9677 people were contacted, of whom 6874 participants met the eligibility criteria of being men aged 55–75 years or women aged 60–75 years, with overweight or

obesity (body mass index (BMI) between 27.0 and 40.0 kg/m²) and meeting at least three criteria for the MetS according to the updated harmonized definition of the International Diabetes Federation and the American Heart Association and National Heart, Lung, and Blood Institute (Alberti et al., 2009); 995 participants were excluded for not having available food frequency questionnaire (FFQ) data on the starting year (baseline), the 2-year follow-up, or both. A final number of 5879 participants were analyzed. Informed written consent was provided by all participants and the study protocol and procedures were approved by ethical committees according to the ethical standards of the Declaration of Helsinki by all the 23 participating institutions.

2.3. Assessment of dietary intake

A validated semi-quantitative 143-item FFQ (Fernández-Ballart et al., 2010; de La Fuente-Arrillaga et al., 2010; Martín-Moreno et al., 1993) was administered by trained dietitians to assess usual dietary intakes at baseline and 2-year-follow up. FFQ included 143 food items and a regular portion size was established for each item. Consumption frequencies were registered according to an incremental scale of nine categories: Never or almost never, 1–3 times per month, once per week, 2–4 times per week, 5–6 times per week, once per day, 2–3 times per day, 4–6 times per day and more than six times per day. The reported frequencies of food consumption were converted into grams of each item intake per day, multiplying it by the weight of the regular portion size indicated using a computer program based on available information from Spanish food composition tables (Moreiras et al., 2015; Mataix et al., 2013). The results determined the amount of food items (in grams) and the energy intake (in kcal) consumed for each participant per day.

2.4. Assessment of the processed food consumed according to the NOVA system

FFQ food items were classified according to the NOVA system, which was created in 2010 by the NUPENS research group at the School of Public Health of the University of Sao Paulo, led by Prof. Carlos Monteiro. It is a system that classifies foods and beverages by their degree of processing, relegating importance to the nutrient composition it contains. It presents four established groups: NOVA 1: Un-processed or minimally processed foods; NOVA 2: Processed culinary ingredients; NOVA 3: Processed foods; and NOVA 4: Ultra-processed foods (Talens et al., 2020; Monteiro et al., 2019a). Once the groups were established, the percentage of UPF consumption was calculated at baseline and 2-year-follow up; the sum of grams from

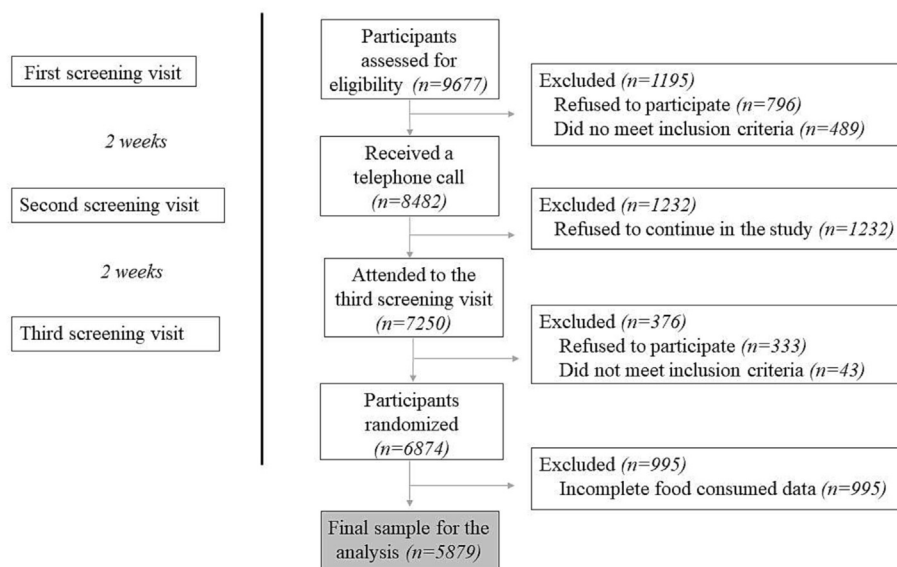


Fig. 1. Flow-chart of eligibility of participants.

UPF products consumed was divided by the total grams of all food items consumed per day, and multiplied by 100, as previously used (Konieczna et al., 2022). Differences in percentage of UPF consumption between baseline and at 2-year follow-up were distributed in tertiles: Tertile 1 (T1): Maximum %UPF reduction: ≤ -37.839 ; Tertile 2 (T2): Medium %UPF reduction: from -3.7838 to -0.5537 ; Tertile 3 (T3): Minimum %UPF reduction: ≥ -0.5536 .

2.5. Sociodemographic characteristics and anthropometric measurements

Information related to sociodemographic characteristics such as sex, age, and educational level (primary school, secondary school, college school technician or bachelor's degree) was self-reported. Anthropometric measurements (body weight, height, waist circumference, and hip circumference) were obtained. Height was measured to the nearest millimeter, with the participant's head maintained in the Frankfurt Horizontal Plane, using a mobile stadiometer (Seca 213, SECA Deutschland, Hamburg, Germany). Weight was measured, with participants wearing light clothes and no shoes (0.6 kg of weight was subtracted for their clothing), using a Segmental Body Composition Analyzer for impedance testing (Tanita MC780P-MA, Tanita, Tokyo, Japan). BMI was calculated following the standard formula weight in kilograms divided by the square of height in meters. Waist circumference (WC) was measured halfway between the last rib and the iliac crest in duplicate with an anthropometric tape with the subjects standing upright; the average value of each measurement was used in the analysis.

2.6. Assessment of adherence to MedDiet

The MedDiet was followed by all participants during the two years of the study. A 17-item energy-reduced MedDiet validated questionnaire (Schröder et al., 2021) was assessed at baseline and after two years to confirm MedDiet adherence at each moment in time and changes during this period. The questionnaire was administered by trained dietitians and consists of 17 questions, each one related to a characteristic item of the MedDiet. If the person surveyed followed the diet correctly in an item, they were given a score of 1 and if they were not, they were given a score of 0. A higher score, with a maximum of 17 points, is considered as a greater MedDiet adherence and a greater quality of the diet.

2.7. Assessment of the physical activity (PA)

The validated Minnesota-REGICOR short PA questionnaire (Elosua et al., 2000; Elosua et al., 1994; Molina et al., 2017) and the validated Spanish version of the Nurses' Health Study questionnaire (Martínez-González et al., 2005) were used to assess PA and sedentary behaviors respectively at baseline and 2-year follow-up.

2.8. GHGs, energy, water, and land use per kg of food

Environmental parameters calculations were done using the Agribalyse® 3.0.1 database created by the French Agency for the Environment an Energy Management (ADEME), in conjunction with the CIQUAL French food composition table (<https://agribalyse.ademe.fr/app/aliments>, 2013; Colomb et al., 2015). Ecoinvent® is also cooperating with Agribalyse® 3.0.1; data is stored in the Ecoinvent database for non-agricultural procedures (e.g., electricity, transport) and imported production; together they aim to reflect the production and market conditions of European countries. The project was launched in 2009 and the database was published in 2021. The Agribalyse® 3.0.1 database provides reference data on the environmental impacts of agricultural and food products through a database built according to the LCA methodology. It considers each phase in the food chain separated in two steps; production and post-farm procedures. Agricultural production, transport, processing, packaging, distribution and retailing, consumer preparation and disposal of packaging are the steps considered to measure environmental impacts. Wastage at

home and transport from retail to the household is not included. The method is based on the international LCA standards: ISO 14040 (ISO 14040:2006(fr), n.d.) and ISO 14044 (ISO 14044:2006(fr), n.d.), LEAP guidelines (<https://www.fao.org/partnerships/leap/overview/the-partnership/en/>, n.d.) and product environmental footprint (PEF) (European Commission, 2018); the final measurements of each environmental indicator are provided per kg of product. A total of 14 indicators with an environmental footprint single score are available. The Agribalyse® 3.0.1 database methodology can be found extensively explained elsewhere (Kesse-Guyot et al., 2023). Total amounts of GHGs, water use, energy use and land use were used for the present paper and are described below.

GHGs were expressed in kilograms (kg) of carbon dioxide equivalents (CO₂eq). Water use was calculated in cubic meters (m³) and in correspondence with water consumption and depletion in certain regions, taking scarcity into account. Energy use was calculated in megajoules (MJ) and corresponded to the disposal of non-renewable energy resources like carbon, gas, oil or uranium. Land use largely determines biodiversity. The unit used for the variable land use was estimated using the echo indicator point (Pt), which reflects the impact of an activity on land biodiversity degradation with reference to the "natural state", meaning that higher levels on land degradation would be reflected with higher Pt units (<https://agribalyse.ademe.fr/app/aliments>, 2013).

All four parameters were estimated at baseline and 2-year follow-up using the following formula:

$$= \frac{\text{g of each reported food} \times \text{Amount of the Environmental Parameter}}{1000 \text{ g of the corresponding food}}$$

The sum of the total impact of the diet was calculated for each parameter separately. The difference between baseline results and two-year results per day was also calculated.

2.9. Statistics

Analyses were performed using SPSS statistical software package version 27.0 (SPSS Inc., Chicago, IL, USA). Data was shown as mean and standard deviation (SD), except for prevalence data, which was expressed as sample size and percentage. Chi-squared test was used for categorical variables and one-way ANOVA and Bonferroni's post-hoc was used for continuous variables. General Linear Model (GLM) was used to relate changes of percentage of UPF consumption and anthropometric characteristics, energy intake, MedDiet adherence, PA and environmental parameters, during the two-year period. GLM was adjusted by sex, age and energy intake, except for the "Energy intake" variable that was only adjusted by sex and age. Bonferroni's post-hoc test was used to show statistically significant differences ($p < 0.05$) between groups within time (a, b, c), between time within groups (*) and between time*group interaction. Linear regressions between percentage of UPF consumption change and GHGs, water use, energy use and land use were conducted. The independent variable was the percentage of UPF consumption change and dependent variables were GHGs, water use, energy use and land use. Fig. 2 shows the linear progression and the regression equation for baseline and 2-year follow-up.

3. Results

Differences on characteristics of sample (sex, educational level, and age) according to changes in UPF consumption in two years are shown in Table 1. T1 (Maximum percentage of UPF reduction) experienced an average reduction of 8.7 %; T2 (Medium percentage of UPF reduction) an average reduction of 2.0 %; and T3 (Minimum percentage of UPF reduction) an average increase of 2.4 %. There were more men in the groups with a maximum (T1) and medium (T2) %UPF reduction in comparison with the minimum reduction group (T3), where there were more women. "Primary School", "Secondary School" and "College School Technician" educational levels were more usual among participants in T1, while more "Bachelor's

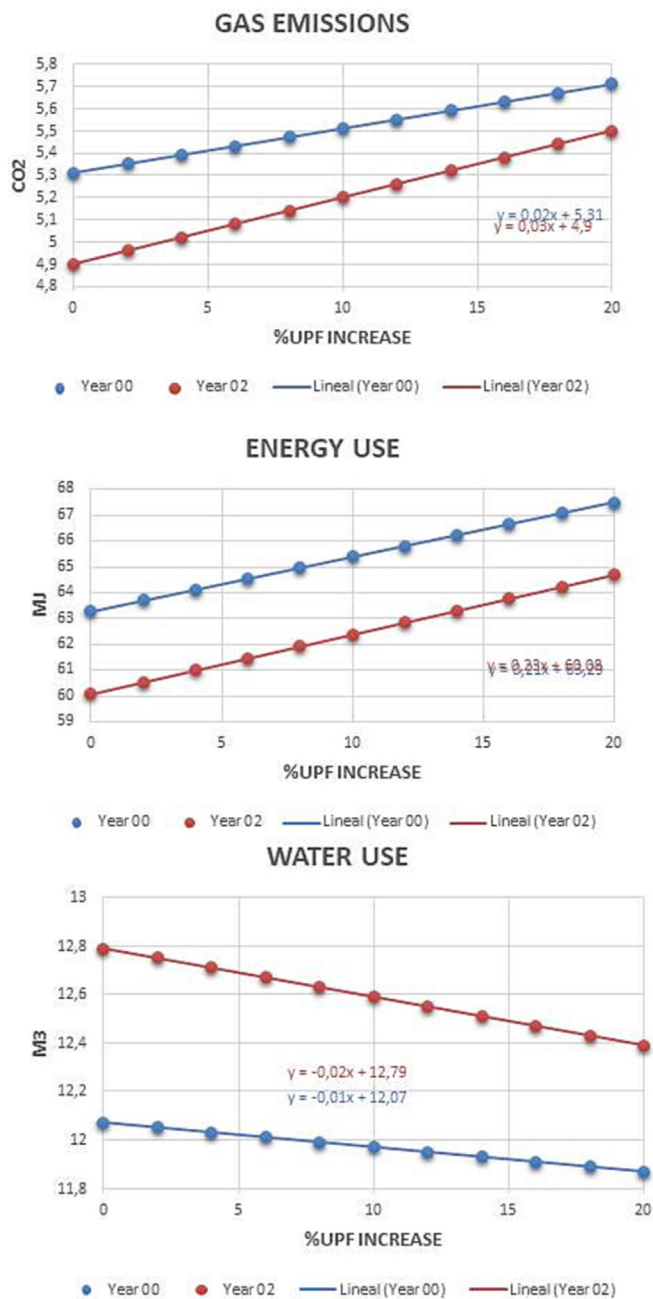


Fig. 2. Linear progression of environmental parameters per years and supposed increase of %UPF consumption.

degree” participants were found in T3. Participants with a major reduction of UPF consumption (T1) were younger.

Table 2 shows the contribution of food groups and NOVA groups, expressed in grams, according to changes in UPF consumption after two-year-follow-up. All food groups' contribution were significant ($p < 0.001$) except for the “eggs” group. T1 showed higher decreases in sweets, red and processed meat, and pre-cooked products, with a significant increase in consumption of fruits and vegetables and a slight increase in white meat, fish, and nuts. T3 showed higher decrease in dairy but lower decrease in red and processed meat and pre-cooked products than T1 and T2, with a decrease in fruits and vegetables and a slight increase in sweets. The four NOVA group categories were also distributed by the mentioned tertiles. T1 showed an average increase of 156.2 g of unprocessed foods and an average decrease of 196.3 g of ultra-processed food while T3 showed an average reduction of 70.8 g of unprocessed foods and an average increase of 48.7 g of ultraprocessed food.

Table 3 shows changes in characteristics of sample through time in weight (kg), BMI (kg/m^2), energy intake (kcal/day), MedDiet adherence, and PA according to the changes in UPF consumption. Weight, BMI and energy intake decreased in all tertiles ($p < 0.001$). There was a decreasing gradient of weight related to tertiles of reduction on UPF consumption, with a mean difference of -2.6 kg, -2.1 kg and, -1.2 kg in T1, T2 and T3, respectively ($p < 0.001$). Likewise, BMI decreased by 0.9 kg/m^2 , 0.7 kg/m^2 , and 0.4 kg/m^2 ($p < 0.001$), and energy intake was reduced by 347 kcal/day, 181 kcal/day, and 94.5 kcal/day respectively in T1, T2 and T3 ($p < 0.001$). MedDiet adherence enhanced in all tertiles ($p < 0.001$), with an increase of 3.9 points in T1, compared to 3.3 and 2.2 points in T2 and T3, respectively ($p < 0.001$). Time per group (time*group) differences were not found significant for physical activity variables except for moderate PA ($p = 0.002$), showing an increase of metabolic equivalents of task (METs) (295.8 min/week) through two years for people with the highest UPF reduction (T1).

Table 4 shows changes through time for GHGs, water use, energy use and land use. Participants in T1 had significantly ($p < 0.001$) higher reductions of GHGs (-0.6 kg CO_2eq compared to -0.3 and -0.3 kg CO_2eq in T2 and T3, respectively), and energy consumption (-5.3 MJ compared -2.8 and -3.1 MJ in T2 and T3, respectively) while their water use increased more over time (0.9 m^3) than in other tertiles (0.8 and 0.3 m^3 in T2 and T3, respectively). Land use appeared to not be significant ($p = 0.840$).

Fig. 2 represents linear trends of the three significative environmental parameters if UPF consumption would have been increased at baseline and 2-year follow-up. Higher percentage of UPF consumption would suppose an increase of GHGs and use of energy and a decrease of water use in both years. Lower amounts of water use, and higher energy consumption and CO_2 emitted would be expected at the 2-year follow-up with respect to baseline if the percentage of UPF increases.

4. Discussion

This study shows that a lower UPF consumption may contribute to environmental sustainability in terms of reducing emissions of GHGs and energy use, while the use of water may be increased.

Recent reviews (Lane et al., 2021; Pagliai et al., 2021) warn that a higher consumption of UPFs is a leading cause for suffering non-communicable diseases, overweight, and obesity. It agrees with current results, since a reduction in BMI, weight, and especially energy intake is observed in participants as reduction of UPF consumption was higher. In an inpatient randomized controlled trial, energy intake and weight gain were higher in participants eating the ultra-processed diet compared to patients following unprocessed diet for two weeks (Hall et al., 2019). Increasing consumption of UPF was reported in both developed and developing countries, reducing overall diet quality and having detrimental health impact (Moubarac et al., 2013; Monteiro et al., 2011). UPF was also related to cancer prevalence (Fiolet et al., 2018; Romaguera et al., 2021), visceral fat deposition (Konieczna et al., 2021) and dysregulation of the gut microbiota affecting cognitive health (Martínez Leo and Segura Campos, 2020).

Food groups were considered in this study to show foods in higher-consumption UPF diets. High level of processed meat in participants' diet was found as a driver for UPF environmental impacts (Anastasiou et al., 2022a). Participants with higher reductions in UPF consumption also had higher reductions of red and processed meat in current study. Dairy products were also contributors to the environmental impact (Seves et al., 2017). However, participants with highest UPF reductions in the current study, showed very slight reductions in dairy consumption. This reflects how the NOVA system classifies food groups according to their processing degree, with milk and yogurt classified as “Unprocessed or minimally processed foods”, and cheeses were classified as “Processed foods”, but none were classified as “Ultra-processed”, nor contributing to the environmental footprint from the processing point of view. The current study shows how UPF may be replaced with moderate amounts of white meat or fish. Moreover, consuming cereals, legumes, fruits and vegetables according to energy needs would be beneficial for people health and the environment.

Table 1
Descriptive characteristics of sample according to changes in ultra-processed food consumption.

| | T1: Maximum %UPF reduction § (n = 1956) n (%) | T2: Medium %UPF reduction § (n = 1956) n (%) | T3: Minimum %UPF reduction § (n = 1956) n (%) | p |
|---------------------------|---|--|---|--------|
| Sex | | | | |
| Men | 1078 (55) | 1002 (51.1) | 959 (49) | 0.001 |
| Women | 881 (45) | 959 (48.9) | 1000 (51) | |
| Educational level | | | | |
| Primary school | 262 (13.4) | 231 (11.8) | 241 (12.3) | 0.030 |
| Secondary school | 184 (9.4) | 174 (8.9) | 167 (8.5) | |
| College school technician | 596 (30.4) | 582 (29.7) | 525 (26.8) | |
| Bachelor's degree | 917 (46.8) | 974 (49.7) | 1026 (52.4) | |
| | Mean (SD) | Mean (SD) | Mean (SD) | p |
| Baseline Age (years) | 64.5 (4.9) | 65.2 (4.7) | 65.3 (4.9) | <0.001 |

Abbreviations: SD: Standard deviation. UPF: Ultra-processed food. T1: Tertile 1. T2: Tertile 2. T3: Tertile 3. § Differences in %UPF consumption between baseline and at 2-year follow-up distributed in tertiles T1: Maximum %UPF reduction: $\leq -37,839$; T2: Medium %UPF reduction: -3.7838 thru -0.5537 ; T3: Minimum %UPF reduction: ≥ -0.5536 . Average changes in %UPF consumption by group were: -8.7% (T1), -2.0% (T2) and $+2.4\%$ (T3). Differences in means between groups were tested by one-way ANOVA and Bonferroni's post hoc (different letters show differences between groups). Differences in prevalence's across groups were examined using χ^2 .

Table 2
Food groups and NOVA groups according to changes in ultra-processed food consumption.

| | | T1: Maximum %UPF reduction § (n = 1956) mean (SD) | T2: Medium %UPF reduction § (n = 1956) mean (SD) | T3: Minimum %UPF reduction § (n = 1956) mean (SD) | Time* group ‡ |
|----------------------------|----------|---|--|---|------------------|
| Dairy (g) | Baseline | 311.7 (191.2) ^{a b} | 334.5 (195.2) ^{a c} | 354.2 (212.5) ^{b c} | <0.001 |
| | 2 year | 307.4 (191.3) ^b | 311.6 (181.9) ^c | 300.1 (179.3) ^{b c} | |
| | ▲ | -0.4 (191.4) ^{d e} | -22.8 (186.2) ^{* d f} | -54.1 (191.0) ^{* e f} | |
| Sweets (g) | Baseline | 91.8 (71.9) ^{a b} | 56.1 (39.0) ^{a c} | 48.8 (43.0) ^{b c} | <0.001 |
| | 2 year | 34.9 (33.6) ^{a b} | 31.7 (29.5) ^{a c} | 50.9 (48.6) ^{b c} | |
| | ▲ | -56.8 (67.6) ^{* d e} | -24.4 (33.4) ^{* d f} | 2.1 (44.5) ^{* e f} | |
| Eggs (g) | Baseline | 24.4 (13.2) | 23.9 (12.2) | 24.3 (11.8) | 0.261 |
| | 2 year | 25.5 (12.3) | 25.4 (11.4) | 25.5 (13.8) | |
| | ▲ | 1.1 (15.5) [*] | 1.5 (13.3) [*] | 1.2 (15.0) [*] | |
| White meat (g) | Baseline | 60.3 (34.3) ^{a b} | 62.3 (33.4) ^a | 64.5 (35.4) ^b | <0.001 |
| | 2 year | 66.2 (30.6) | 68.4 (31.1) ^c | 65.4 (31.3) ^c | |
| | ▲ | 5.8 (37.3) ^{* e} | 6.1 (35.8) ^{* f} | 0.9 (38.4) ^{e f} | |
| Red and processed meat (g) | Baseline | 97.7 (54.3) ^{a b} | 84.8 (43.9) ^{a c} | 80.6 (43.6) ^{b c} | <0.001 |
| | 2 year | 61.4 (36.7) ^b | 60.9 (36.4) ^c | 69.3 (40.0) ^{b c} | |
| | ▲ | -36.3 (53.8) ^{* d e} | -23.9 (44.3) ^{* d f} | -11.2 (44.4) ^{* e f} | |
| Fish and seafood (g) | Baseline | 100.2 (47.4) ^{a b} | 103.8 (47.3) ^a | 105.9 (48.9) ^b | <0.001 |
| | 2 year | 110.3 (46.6) ^b | 110.4 (44.1) ^c | 106.0 (46.9) ^{b c} | |
| | ▲ | 10.0 (54.0) ^{* d e} | 6.6 (50.3) ^{* d f} | 0.15 (53.0) ^{e f} | |
| Fruits and vegetables (g) | Baseline | 651.8 (264.9) ^{a b} | 727.0 (264.7) ^{a c} | 759.5 (311.2) ^{b c} | <0.001 |
| | 2 year | 781.0 (266.0) ^b | 808.2 (267.2) ^c | 752.5 (253.6) ^{b c} | |
| | ▲ | 129.2 (312.9) ^{* d e} | 81.1 (311.6) ^{* d f} | -7.0 (332.4) ^{* e f} | |
| Cereals and legumes (g) | Baseline | 241.5 (100.9) ^{a b} | 247.6 (100.9) ^a | 243.1 (101.7) ^b | <0.001 |
| | 2 year | 215.7 (82.8) ^b | 216.3 (80.4) ^c | 214.6 (83.7) ^{b c} | |
| | ▲ | -25.7 (111.2) ^{* d e} | -31.3 (107.9) ^{* d f} | -28.5 (111.44) ^{* e f} | |
| Nuts (g) | Baseline | 17.1 (19.5) ^{a b} | 18.4 (21.0) ^a | 19.2 (22.4) ^b | <0.001 |
| | 2 year | 30.6 (21.9) ^b | 31.0 (21.3) ^c | 28.5 (21.8) ^{b c} | |
| | ▲ | 13.5 (25.9) ^{* d e} | 12.5 (25.5) ^{* d f} | 9.3 (26.7) ^{* e f} | |
| Pre-cooked products (g) | Baseline | 11.4 (17.3) ^{a b} | 7.0 (9.9) ^a | 6.4 (10.3) ^b | <0.001 |
| | 2 year | 5.1 (9.2) ^{a b} | 4.4 (7.9) ^{a c} | 6.1 (9.9) ^{b c} | |
| | ▲ | -6.2 (16.1) ^{* d e} | -2.6 (9.8) ^{* d f} | -0.2 (11.2) ^{* e f} | |
| Un-processed (g) | Baseline | 1339.4 (394.8) ^{a b} | 1452.1 (397.2) ^{a c} | 1514.2 (444.2) ^{b c} | <0.001 |
| | 2 year | 1495.6 (388.8) ^b | 1520.8 (367.2) ^c | 14,443.3 (366.2) ^{b c} | |
| | ▲ | 156.2 (430.1) ^{* d e} | 68.7 (411.5) ^{* d f} | -70.8 (436.7) ^{* e f} | |
| Mini-processed (g) | Baseline | 53.4 (23.2) ^{a b} | 52.9 (21.6) ^a | 52.1 (22.2) ^b | 0.008 |
| | 2 year | 51.0 (18.6) | 52.0 (17.9) ^c | 51.7 (18.7) ^c | |
| | ▲ | -2.3 (24.1) ^e | -0.8 (22.9) [*] | -0.4 (22.9) ^{* e} | |
| Processed (g) | Baseline | 421.4 (276.0) ^{a b} | 428.8 (289.1) ^{a c} | 446.2 (326.5) ^{b c} | <0.001 |
| | 2 year | 342.6 (237.1) ^a | 355.3 (238.6) ^a | 361.4 (246.3) | |
| | ▲ | -78.7 (243.0) ^{* d e} | -73.4 (239.2) ^{* d f} | -84.8 (267.9) ^{* e f} | |
| Ultra-processed (g) | Baseline | 287.0 (209.2) ^{a b} | 114.5 (80.4) ^{a c} | 103.3 (99.1) ^{b c} | <0.001 |
| | 2 year | 90.7 (99.6) ^{a b} | 71.6 (70.4) ^{a c} | 152.0 (156.0) ^{b c} | |
| | ▲ | -196.3 (165.3) ^{* d e} | -42.8 (34.3) ^{* d f} | 48.7 (101.2) ^{* e f} | |

Abbreviations: SD: Standard deviation. UPF: Ultra-processed food. T1: Tertile 1. T2: Tertile 2. T3: Tertile 3. § Differences in %UPF consumption between baseline and at 2-year follow-up distributed in tertiles: T1: Maximum %UPF reduction: $\leq -37,839$; T2: Medium %UPF reduction: -3.7838 thru -0.5537 ; T3: Minimum %UPF reduction: ≥ -0.5536 . Average changes in %UPF consumption by group were: -8.7% (T1), -2.0% (T2) and $+2.4\%$ (T3). General Linear Model was calculated between baseline and year 2 follow-up adjusted by age, sex and energy intake. Different letters show significant differences ($p < 0.05$) between groups within time (a, b, c), between time within groups (*) and between time*group interaction (d, e, f) by the Bonferroni post-hoc test ($p < 0.05$).

Table 3
Changes in characteristics of sample according to the level of reduction in UPF consumption.

| | | T1: Maximum %UPF reduction § (n = 1956) | T2: Medium %UPF reduction § (n = 1956) | T3: Minimum %UPF reduction § (n = 1956) | Time* group ‡ |
|--------------------------|----------|---|--|---|---------------|
| | | mean (SD) | mean (SD) | mean (SD) | |
| Weight | Baseline | 87.1 (13) | 85.8 (12.7) | 85.6 (13) | <0.001 |
| | 2 year | 84.4 (13.3) ^b | 83.7 (12.9) | 84.3 (13.4) ^b | |
| | ▲ | -2.6 (4.7) ^{* d e} | -2.1 (4.5) ^{* d f} | -1.2 (4.4) ^{* e f} | |
| BMI (kg/m ²) | Baseline | 32.5 (3.4) | 32.4 (3.4) | 32.3 (3.4) | <0.001 |
| | 2 year | 31.6 (3.7) ^b | 31.6 (3.6) | 31.9 8 (3.7) ^b | |
| | ▲ | -0.9 (1.7) ^{* d e} | -0.7 (1.7) ^{* d f} | -0.4 (1.6) ^{* e f} | |
| Med-Diet ADH | Baseline | 7.8 (2.5) ^{a b} | 8.7 (2.6) ^{a c} | 8.9 (2.7) ^{b c} | <0.001 |
| | 2 year | 11.8 (2.8) ^b | 12 (2.6) ^c | 11.1 82.7) ^{b c} | |
| | ▲ | 3.9 (3.2) ^{* d e} | 3.3 (3.1) ^{* d f} | 2.2 (3.1) ^{* e f} | |
| Energy (kcal/day) | Baseline | 2529.1 (679) ^{a b} | 2372.6 (570.2) ^a | 2351 (591.6) ^b | <0.001 |
| | 2 year | 2182 (505.5) ^b | 2191.6 (461.3) ^c | 2256.5 (509.3) ^{b c} | |
| | ▲ | -347 (664.8) ^{* d e} | -181 (535.5) ^{* d f} | -94.5 (570.2) ^{* e f} | |
| Light PA (METs)† | Baseline | 809.5 (982.4) ^b | 782.1 (979.9) | 735.9 (918) ^b | 0.406 |
| | 2 year | 899 (1054.7) | 898.1 (1001.9) | 881.4 (960.6) | |
| | ▲ | 89.5 (1229) [*] | 115.9 (1171.4) [*] | 145.2 (1142.1) [*] | |
| Moderate PA (METs)† | Baseline | 850.9 (1355.8) ^{a b} | 1018.6 (1563.1) ^a | 1053.4 (1683.4) ^b | 0.007 |
| | 2 year | 1146.8 (1591.5) | 1207.9 (1690.6) | 1144.6 (1852.7) | |
| | ▲ | 295.8 (1607.1) ^{* e} | 189.3 (1746.2) [*] | 91.7 (1729.5) ^{* e} | |
| Intense PA (METs)† | Baseline | 720 (1375.7) | 786.7 (1447.7) | 816.5 (1485) | 0.862 |
| | 2 year | 952.7 (1615.3) | 1001.3 (1626.2) | 1004.2 (1784.7) | |
| | ▲ | 232.6 (1656.5) [*] | 214.6 (1635.7) [*] | 187.8 (1773.5) [*] | |
| Total PA (METs)† | Baseline | 2380.5 (2174.9) ^{a b} | 2587.5 (2319.1) ^a | 2605.9 (2469.3) ^b | 0.189 |
| | 2 year | 2998.6 (2420.3) | 3107.4 (2504.3) | 3030.2 (2684.9) | |
| | ▲ | 618.1 (2515.6) [*] | 519.9 (2464.5) [*] | 424.8 (2692.9) [*] | |

Abbreviations: BMI: Body Mass Index. Med-Diet ADH: Mediterranean Diet Adherence. PA: Physical Activity. SD: Standard deviation. UPF: Ultra-processed food. T1: Tertile 1. T2: Tertile 2. T3: Tertile 3. † Measured in METs (Metabolic equivalents of task) min/week. § Differences in %UPF consumption between baseline and at 2-year follow-up distributed in tertiles: T1: Maximum %UPF reduction: $\leq -37,839$; T2: Medium %UPF reduction: -3.7838 thru -0.5537 ; T3: Minimum %UPF reduction: ≥ -0.5536 . Average changes in %UPF consumption by group were: -8.7 % (T1), -2.0 % (T2) and +2.4 % (T3). General Lineal Model was calculated between baseline and year 2 follow-up adjusted by age, sex and energy intake. Variable: "Energy (kcal/day)" was only adjusted by age, and sex. Different letters show significant differences ($p < 0.05$) between groups within time (a, b, c), between time within groups (*) and between time*group interaction (d, e, f) by the Bonferroni post-hoc test ($p < 0.05$).

Higher adherence to the MedDiet was found in the current study to be a strategy for reducing UPF consumption (García et al., 2023). This is explained by the defining fact that MedDiet, beyond nutritional content considerations commented elsewhere (Fardet and Rock, 2020a), is made up of mainly fresh products, with a low level of processing. A linear association of MedDiet with a sustainability score had already been described considering the same four environmental parameters in the current study (Grosso et al., 2020), demonstrating that a higher MedDiet adherence was specifically related with lower GHGs (García et al., 2023; Grosso et al., 2020).

A previous study on GHGs, and use of water, land, and energy found similar results, being notable in terms of water use (Fresán et al., 2020). Less ultra-processed diets like MedDiet, which is based on plant-based food groups, were also associated with greater amount of water use. This may be due to the fact that growing vegetables, fresh fruits and nuts need higher amount of water, although it is not as applicable to cereals and legumes, as these are mostly dryland crops (Fresán et al., 2020). This is consistent with the results of a recent study conducted in the Netherlands which found that higher UPF consumption was associated with higher

Table 4
Changes in environmental impacts according to the level of reduction in UPF consumption.

| | | T1: Maximum %UPF reduction § (n = 1956) | T2: Medium %UPF reduction § (n = 1956) | T3: Minimum %UPF reduction § (n = 1956) | Time* group ‡ |
|------------------------------|----------|---|--|---|---------------|
| | | mean (SD) | mean (SD) | mean (SD) | |
| GHGs (Kg CO ₂ eq) | Baseline | 5.5 (1.5) ^b | 5.3 (1.4) | 5.4 (1.4) ^b | 0.006 |
| | 2 year | 4.9 (1.2) | 5 (1.2) | 5.1 (1.2) | |
| | ▲ | -0.6 (1.5) ^{* e} | -0.3 (1.3) [*] | -0.3 (1.3) ^{* e} | |
| Water Use (m ³) | Baseline | 11.7 (3.9) ^{a b} | 11.9 (3.9) ^{a c} | 12.1 (4.2) ^{b c} | <0.001 |
| | 2 year | 12.6 (3.9) ^b | 12.8 (3.7) ^c | 12.5 (3.6) ^{b c} | |
| | ▲ | 0.9 (4.7) ^{* d e} | 0.8 (4.6) ^{* d f} | 0.3 (4.7) ^{e f} | |
| Energy Use (MJ) | Baseline | 66.1 (17.1) ^{a b} | 63.9 (15.6) ^{a c} | 65 (16.2) ^{b c} | <0.001 |
| | 2 year | 60.8 (14.4) | 61.1 (13.3) | 61.8 (14.3) | |
| | ▲ | -5.3 (17.2) ^{* e} | -2.8 (15) ^{* f} | -3.1 (15.7) ^{* e f} | |
| Land Use (Pt) | Baseline | 281.0 (88.9) ^b | 271.9 (82.3) | 271.8 (82.2) ^b | 0.840 |
| | 2 year | 239.8 (72.5) | 243.4 (72.1) | 249.6 (73.9) | |
| | ▲ | -41.1 (87.4) [*] | -28.5 (77.5) [*] | -22.1 (80.8) [*] | |

Abbreviations: SD: Standard deviation. GHGs: Greenhouse gas emissions. Kg CO₂eq: Kilograms of Carbon Dioxide equivalents. m³: Cubic meters; MJ: Megajoules. Pt: points of land use. UPF: Ultra-processed food. T1: Tertile 1. T2: Tertile 2. T3: Tertile 3 § Differences in %UPF consumption between baseline and at 2-year follow-up distributed in tertiles: T1: Maximum %UPF reduction: $\leq -37,839$; T2: Medium %UPF reduction: -3.7838 thru -0.5537 ; T3: Minimum %UPF reduction: ≥ -0.5536 . Average changes in %UPF consumption by group were: -8.7 % (T1), -2.0 % (T2) and +2.4 % (T3). General Lineal Model was calculated between baseline and after 2-year follow-up adjusted by age, sex and energy intake. Different letters show significant differences ($p < 0.05$) between groups within time (a, b, c), between time within groups (*) and between time*group interaction (d, e, f) by the Bonferroni post-hoc test ($p < 0.05$).

GHGs and lower water use, and thus the replacement of UPF by unprocessed and minimally processed foods may suppose increases in water use (Vellinga et al., 2022). A Brazilian study found initial linear associations between UPF and water footprints. After adjusting by total energy intake, associations vanished, indicating that dietary contributions of UPF increase the use of water because of the indirect increment on energy intake (Garzillo et al., 2022). Current results were also adjusted by energy intake and are aligned with the results of both studies in the Netherlands and Brazil. Another previous paper found how the negative association regarding to water use was strengthened when adjustments by energy intake were conducted (Kesse-Guyot et al., 2023). Energy intake should be considered when talking about UPF sustainability. It is one of the main drivers of negative environmental impact, and a primary characteristic of UPF-rich diets; a 15 % of overweight/obesity could be attributed to consumption of >17 % of energy intake from UPF (Canhada et al., 2020).

Land use was not significative in the current study. Land-use impacts from UPF are mainly driven by processed meat products; relatively low contributions were found to land use for meat-free UPF products when compared to processed meat products (Anastasiou et al., 2022a). The contribution of red and processed meat and pre-cooked foods is low in the current participants' diets, since they tend to follow the MedDiet. Even if a notable higher decrease can be seen in the group which reduced UPF the most, all three groups showed reductions on those food groups, which explain the lack of association between UPF and land use.

There is still considerable inter-study variability in the environmental impact results regarding to UPF, which depends on the food classification used, the production steps accounted for, whether processed meat is included, and whether proper energy intake adjustments are made. The results for GHGs and energy use seem to be more consistent, indicating how UPF is one of the major contributors to these parameters when compared to other food groups (Anastasiou et al., 2022a; Anastasiou et al., 2022b).

In a study on UPF environmental impact in Brazil from 1987 to 2018, diet-related GHGs increased by 21 %, diet-related water footprint increased by 22 % and diet-related ecological footprint increased by 17 %; products from the fourth NOVA group (UPF and drinks) were primarily responsible for these changes (da Silva et al., 2021). The Food and Agriculture Organization (FAO) indicated that UPF consumption in Australia represent a third of the diet-related environmental effects corresponding to a 35 % of water use, 39 % of energy use, 33 % of CO₂eq and 35 % of land use, which could double in GHGs per capita by 2050 if dietary trends continue as projected (Machado et al., 2019; Monteiro et al., 2019b). Even though the highest emission of GHGs was still due to animal products (meat and dairy) (Seves et al., 2017; Fresán et al., 2020; Clonan et al., 2015; Notarnicola et al., 2017) in comparison with plant and low-calorie processed products, UPF were associated with intensive agriculture and livestock practices that threaten the sustainability of the food system (Fardet and Rock, 2020b).

In a recent study on Spanish adult population attitudes about a sustainable diet, participants attributed the main negative environmental impact to processed foods and beverages, and men appeared to have a better understanding in relation to the term sustainability (García-González et al., 2020). A very recent review of different policies on reducing UPF consumption concluded that policies such as taxation, marketing or subsidies would be beneficial for the climate-environment-related sustainability as well as health (Popkin et al., 2021).

In a healthy and sustainable diet, it is highly recommended to include the recommendations of UNESCO and the Sustainable Development Goals from the United Nations System (United Nations (UN), n.d.), which advocate for recovering the traditional diet patterns of each region appropriate to the climate, natural resources, and cultural heritage, with some modifications when necessary to complement them nutritionally. In this way, the recent update of the MedDiet pyramid (Serra-Majem et al., 2020) is also aligned with the guidelines of the global food model proposed by the EAT Lancet study for 2050 (Willett et al., 2019). A holistic process to include sustainability, and specifically UPF environmental impacts, needs to be adequately integrated into FDGD so that society has appropriate guidelines on how to identify and consume these kind of products (Mazac et al., 2021).

5. Strengths and limitations

The longitudinal design allowing for causality evaluation is the first strength of this study, followed by the great sample used. The use of the NOVA system for food classification permits comparison with other studies that considered this same system. Environmental parameters calculations for each participant diet were based in a French actualized database that considered each step of the LCA; agricultural production, transport, processing, packaging, distributions and retailing, consumer and disposal of packaging are the steps considered to measure environmental impacts. The use of four environmental parameters like GHGs, water use, energy use, and land use represents one of the greatest strengths of the paper, which permits a holistic evaluation of environmental impact.

The first limitation for this study is the lack of a validated questionnaire that measures UPF consumption. The use of the FFQ provides an overview, but it is not precisely assessing UPF consumption. For example, fruit juices, milkshakes, meatballs, hamburgers and pizza can be consumed as artisanal, but here they were also considered industrial and classified as ultra-processed products. FFQ does not distinguish between plain, sweetened, or flavored varieties of yogurts and whole-grain cereals so these foods were considered to belong to unprocessed or minimally processed foods group. The use of the unit "Pt" for land calculations may be a limitation, since it is a specific calculation that cannot be compared to other articles that do not use the Agribalyse® 3.0.1 database. Spain does not currently have its own database for food environmental impacts. Using a French database instead of a Spanish one can be a limitation since there can be differences in the food supply between countries which may result in slight changes to the environmental values. However, we determined that Agribalyse® 3.0.1 was an appropriate option since the European Union has a market regulated by the Treaty on the Functioning of the European Union (TFEU) with the objective to establish a common internal market. Additionally, the EU food market is specifically regulated as well. Regulation (EC) No. 178/2002 of the European Parliament and of the Council of January 28, 2002, declares that food circulation between member states of the European Union should be based on common concepts, principles, and procedures; free movement of food and feed within the EU is only allowed if the food and feed safety requirements do not differ significantly from one Member State to another. Finally, the study population age is in between 55–75 for men and 60–75 for women which is an impediment for extrapolating our data to a younger population.

6. Conclusions

The current study demonstrated that low consumption of ultra-processed foods may contribute to environmental sustainability. The processing threshold of the food consumed should be considered not only for nutritional advice on health but also for environmental protection.

Ethics approval and consent to participate

Informed written consent was provided by all participants and the study protocol and procedures were approved by ethical committees according to the ethical standards of the Declaration of Helsinki by all the 23 participating institutions.

Consent for publication

Informed consent was obtained from all subjects involved in the study. The results and writing of this manuscript followed the Committee on Publication Ethics (COPE) guidelines on how to deal with potential acts of misconduct, maintaining the integrity of the research and its presentation following the rules of good scientific practice, the trust in the journal, the professionalism of scientific authorship, and the entire scientific endeavour. Written informed consent has been obtained from the patient(s) to publish this paper.

CRedit authorship contribution statement

All the PREDIMED-Plus investigators (SG, RP, MM-M, LA, MR, MAM-G, JS-S, DC, AG, JV, DR, JL-M, RE, FJT, JL, LS-M, BR-G, XP, JJG, PM, JV, CV, LD, ER, CS-O, PG-S, CV-H, RC, IA, LG-G, EG-G, SC-B, CT-M, AC, JMS-L, JCC, RB, NK, OC, MAZ, JV-L, MB-R, SH-D, RC, JAT, VM-S, CB) contributed to study concept and design and to data extraction from the participants. SG, and CB performed the statistical analyses. SG, CB, and JAT drafted the manuscript. All authors reviewed the manuscript for important intellectual content and approved the final version to be published.

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.

Declaration of competing interest

This work was supported by the official Spanish Institutions for funding scientific biomedical research, CIBER Fisiopatología de la Obesidad y Nutrición (CIBEROBN) and Instituto de Salud Carlos III (ISCIII), through the Fondo de Investigación para la Salud (FIS), which is co-funded by the European Regional Development Fund (six coordinated FIS projects led by JS-S and JVi, including the following projects: PI13/00673, PI13/00492, PI13/00272, PI13/01123, PI13/00462, PI13/00233, PI13/02184, PI13/00728, PI13/01090, PI13/01056, PI14/01722, PI14/00636, PI14/00618, PI14/00696, PI14/01206, PI14/01919, PI14/00853, PI14/01374, PI14/00972, PI14/00728, PI14/01471, PI16/00473, PI16/00662, PI16/01873, PI16/01094, PI16/00501, PI16/00533, PI16/00381, PI16/00366, PI16/01522, PI16/01120, PI17/00764, PI17/01183, PI17/00855, PI17/01347, PI17/00525, PI17/01827, PI17/00532, PI17/00215, PI17/01441, PI17/00508, PI17/01732, PI17/00926, PI19/00957, PI19/00386, PI19/00309, PI19/01032, PI19/00576, PI19/00017, PI19/01226, PI19/00781, PI19/01560, PI19/01332, PI20/01802, PI20/00138, PI20/01532, PI20/00456, PI20/00339, PI20/00557, PI20/00886, PI20/01158); the Especial Action Project entitled: Implementación y evaluación de una intervención intensiva sobre la actividad física Cohorte PREDIMED-Plus grant to JS-S; the European Research Council (Advanced Research Grant 2014–2019; agreement #340918) granted to MÁM-G.; the Recercaixa (number 2013ACUP00194) grant to JS-S; grants from the Consejería de Salud de la Junta de Andalucía (PI0458/2013, PS0358/2016, PI0137/2018); the PROMETEO/2017/017 and the AICO/2021/347 grants from the Generalitat Valenciana; the SEMERGEN grant. J.S-S is partially supported by ICREA under the ICREA Academia programme. C.B. was granted by Juan de la Cierva grant. P.M.G. was granted by the Specialist Postdoctoral program of the Consejería de Salud y Familias, Junta de Andalucía (Spain). None of the funding sources took part in the design, collection, analysis, interpretation of the data, or writing the report, or in the decision to submit the manuscript for publication.

J.S.-S. reported receiving research support from the Instituto de Salud Carlos III, Ministerio de Educación y Ciencia, the European Commission, the USA National Institutes of Health; receiving consulting fees or travel expenses from Eroski Foundation and Instituto Danone, receiving nonfinancial support from Hojiblanca, Patrimonio Comunal Olivarero, the California Almond Board of California, Pistachio Growers and Borges S.A.; serving on the board of and receiving grant support through his institution from the International Nut and Dried Foundation and the Eroski Foundation; and personal fees from Instituto Danone Spain; Serving in the Board

of Danone Institute International. D.C. reported receiving grants from Instituto de Salud Carlos III. R.E. reported receiving grants from Instituto de Salud Carlos III, Fundación Dieta Mediterránea and Cerveza y Salud and olive oil for the trial from Fundación Patrimonio Comunal Olivarero and personal fees from Brewers of Europe, Fundación Cerveza y Salud, Interprofesional del Aceite de Oliva, Instituto Cervantes in Albuquerque, Milano and Tokyo, Pernod Ricard, Fundación Dieta Mediterránea (Spain), Wine and Culinary International Forum and Lilly Laboratories; non-financial support from Sociedad Española de Nutrición and Fundación Bosch y Gimpera; and grants from Uriach Laboratories. The rest of the authors have declared that no competing interests exist. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Acknowledgements

We thank all PREDIMED-Plus participants and investigators. CIBEROBN, CIBERESP, and CIBERDEM are initiatives of the Instituto de Salud Carlos III (ISCIII), Madrid, Spain. The Hojiblanca (Lucena, Spain) and Patrimonio Comunal Olivarero (Madrid, Spain) food companies donated extra-virgin olive oil. The Almond Board of California (Modesto, CA), American Pistachio Growers (Fresno, CA), and Paramount Farms (Wonderful Company, LLC, Los Angeles, CA) donated nuts for the PREDIMED-Plus pilot study.

References

- Alberti, K.G., Eckel, R.H., Grundy, S.M., Zimmet, P.Z., Cleeman, J.I., Donato, K.A., et al., 2009. Harmonizing the metabolic syndrome: a joint interim statement of the international Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation* 120 (16), 1640–1645.
- Anastasiou, K., Baker, P., Hadjidakou, M., Hendrie, G.A., Lawrence, M., 2022a. A conceptual framework for understanding the environmental impacts of ultra-processed foods and implications for sustainable food systems. *J. Clean. Prod.* 368, 133155.
- Anastasiou, K., Baker, P., Hendrie, G.A., Hadjidakou, M., Boylan, S., Chaudhary, A., et al., 2022b. Conceptualising the drivers of ultra-processed food production and consumption and their environmental impacts: a group model-building exercise. SSRN [Preprint]. [consulted 29 April 2023].: 95p. Available in: <https://ssrn.com/abstract=4306622>.
- Baker, P., Machado, P., Santos, T., Sievert, K., Backholer, K., Hadjidakou, M., et al., 2020. Ultra-processed foods and the nutrition transition: global, regional and national trends, food systems transformations and political economy drivers. *Obes. Rev.* 21 (12), e13126.
- Canhada, S., Luft, V.C., Giatti, L., Duncan, B.B., Chor, D., da Fonseca, M.J.M., Matos, S.M.A., Molina, M.D.C.B., Barreto, S.M., Levy, R.B., Schmidt, M.I., 2020. Ultra-processed foods, incident overweight and obesity, and longitudinal changes in weight and waist circumference: the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil). *Public Health Nutr.* 23, 1076–1086.
- Clonan, A., Wilson, P., Swift, J.A., Leibovici, D.G., Holdsworth, M., 2015. Red and processed meat consumption and purchasing behaviours and attitudes: impacts for human health, animal welfare and environmental sustainability. *Public Health Nutr.* 18 (13), 2446–2456.
- Colomb V, Colsaet A, Ait-Amar S, Basset-Mens C, Mevel G, To V, et al. 2015 AGRIBALYSE: the French public LCI database for agricultural products. [Accessed May 02, 2023]. Available in: 10.13140/RG.2.1.2586.0240
- Elosua, R., Marrugat, J., Molina, L., Pons, S., Pujol, E., 1994. Validation of the Minnesota Leisure Time Physical Activity Questionnaire in Spanish men. *Am. J. Epidemiol.* 139 (12), 1197–1209.
- Elosua, R., García, M., Aguilar, A., Molina, L., Covas, M.I., Marrugat, J., 2000. Validation of the Minnesota leisure time physical activity questionnaire in Spanish women. *Med. Sci. Sports Exerc.* 32 (8), 1431–1437.
- European Commission, 2018. Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs) - version 6.3. [Accessed May 02, 2023]. Available in: https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf.
- Fardet, A., Rock, E., 2020a. How to protect both health and food system sustainability? A holistic 'global health'-based approach via the 3V rule proposal. *Public Health Nutr.* 23 (16), 3028–3044.
- Fardet, A., Rock, E., 2020b. Ultra-processed foods and food system sustainability: what are the links? *Sustainability* 12 (15), 6280.
- Fernández-Ballart, J.D., Piñol, J.L., Zazpe, I., Corella, D., Carrasco, P., Toledo, E., et al., 2010. Relative validity of a semi-quantitative food-frequency questionnaire in an elderly Mediterranean population of Spain. *Br. J. Nutr.* 103 (12), 1808–1816.
- Fiolet, T., Srour, B., Sellem, L., Kesse-Guyot, E., Allès, B., Méjean, C., et al., 2018. Consumption of ultra-processed foods and cancer risk: results from NutriNet-Santé prospective cohort. *BMJ* 360, k322.
- Fresán, U., Craig, W.J., Martínez-González, M.A., Bes-Rastrollo, M., 2020. Nutritional quality and health effects of low environmental impact diets: the "Seguimiento Universidad de Navarra" (SUN) cohort. *Nutrients* 12 (8), 2385.

- García, S., Bouzas, C., Mateos, D., Pastor, R., Álvarez, R., Rubín, M., et al., 2023. Carbon dioxide (CO₂) emissions and adherence to Mediterranean diet in an adult population: the Mediterranean diet index as a pollution level index. *Environ. Health* 22 (1), 1.
- García-González, Á., Achón, M., Carretero Krug, A., Varela-Moreiras, G., Alonso-Aperte, E., 2020. Food sustainability knowledge and attitudes in the Spanish adult population: a cross-sectional study. *Nutrients* 12 (10), 315445.
- Garzillo, J.M.F., Poli, V.F.S., Leite, F.H.M., Steele, E.M., Machado, P.P., da Costa Louzada, M.L., et al., 2022. Ultra-processed food intake and diet carbon and water footprints: a national study in Brazil. *Rev. Saude Publica* 56, 6.
- Grosso, G., Fresán, U., Bes-rastrollo, M., Marventano, S., Galvano, F., 2020. Environmental impact of dietary choices: role of the Mediterranean and other dietary patterns in an Italian cohort. *Int. J. Environ. Res. Public Health* 17 (5), 1468.
- Hall, K.D., Ayuketah, A., Brychta, R., Cai, H., Cassimatis, T., Chen, K.Y., et al., 2019. Ultra-processed diets cause excess calorie intake and weight gain: an inpatient randomized controlled trial of ad libitum food intake. *Cell Metab.* 30 (1), 67–77.e3.
- AGRI-BALYSE database of environmental impact indicators for food items produced and consumed in France. France. (updated on 2021; accessed on May 11, 2022). Available from: <https://agribalyse.ademe.fr/app/aliments>.
- Livestock Environmental Assessment and Performance (LEAP) Partnership - Food and Agriculture Organization of the United Nations. [Accessed May 02, 2023]. Available in: <https://www.fao.org/partnerships/leap/overview/the-partnership/en/>.
- ISO 14040:2006(fr) n.d., Management environnemental — Analyse du cycle de vie — Principes et cadre. iso.org. [Accessed May 02, 2023]. Available in: <https://www.iso.org/obp/ui/fr/#iso:std:iso:14040:ed-2:v1:fr>
- ISO 14044:2006(fr) n.d., Management environnemental — Analyse du cycle de vie Exigences et lignes directrices. iso.org [Accessed May 02, 2023]. Available in: <https://www.iso.org/obp/ui/fr/#iso:std:iso:14044:ed-1:v1:fr>
- Kesse-Guyot, E., Allès, B., Brunin, J., Fouillet, H., Dussiot, A., Berthy, F., et al., 2023. Environmental impacts along the value chain from the consumption of ultra-processed foods. *Nat. Sustain.* 6, 192–202.
- Konieczna, J., Morey, M., Abete, I., Bes-Rastrollo, M., Ruiz-Canela, M., Vioque, J., et al., 2021. Contribution of ultra-processed foods in visceral fat deposition and other adiposity indicators: prospective analysis nested in the PREDIMED-Plus trial. *Clin. Nutr.* 40 (6), 4290–4300.
- Konieczna, J., Fiol, M., Colom, A., Martínez-González, M.A., Salas-Salvadó, J., Corella, D., et al., 2022. Does consumption of ultra-processed foods matter for liver health? Prospective analysis among older adults with metabolic syndrome. *Nutrients* 14 (19), 4142.
- de La Fuente-Arillaga, C., Ruiz, Z.V., Bes-Rastrollo, M., Sampson, L., Martínez-González, M.A., 2010. Reproducibility of an FFQ validated in Spain. *Public Health Nutr.* 13 (9), 1364–1372.
- Lane, M.M., Davis, J.A., Beattie, S., Gómez-Donoso, C., Loughman, A., O’Neil, A., et al., 2021. Ultra-processed food and chronic noncommunicable diseases: a systematic review and meta-analysis of 43 observational studies. *Obes. Rev.* 22 (3), e13146.
- Macdiarmid, J.I., 2013. Is a healthy diet an environmentally sustainable diet? *Proc. Nutr. Soc.* 72 (1), 13–20.
- Machado, P.P., Steele, E.M., Levy, R.B., Sui, Z., Woods, J., Gill, T.P., Scrinis, G., Monteiro, C.A., 2019. Ultra-processed foods and recommended intake levels of nutrients linked to non-communicable diseases in Australia: evidence from a nationally representative cross-sectional study. *BMJ Open* 9 (8), e209544.
- Martínez Leo, E.E., Segura Campos, M.R., 2020. Effect of ultra-processed diet on gut microbiota and thus its role in neurodegenerative diseases. *Nutrition*. 71, 110609.
- Martínez-González, M.A., López-Fontana, C., Varo, J.J., Sánchez-Villegas, A., Martínez, J.A., 2005. Validation of the Spanish version of the physical activity questionnaire used in the Nurses’ Health Study and the Health Professionals’ Follow-up Study. *Public Health Nutr.* 8 (7), 920–927.
- Martínez-González, M.A., Buil-Cosiales, P., Corella, D., Bulló, M., Fitó, M., Vioque, J., et al., 2019. Cohort profile: design and methods of the PREDIMED-plus randomized trial. *Int. J. Epidemiol.* 48 (2), 387–388o.
- Martin-Moreno, J.M., Boyle, P., Gorgojo, L., Maisonneuve, P., Fernandez-Rodriguez, J.C., Salvini, S., et al., 1993. Development and validation of a food frequency questionnaire in Spain. *Int. J. Epidemiol.* 22 (3), 512–519.
- Mataix, J., Mañas, M., Llopis, J., Martínez de Victoria, E., Juan, J., Borregón, A., 2013. Tablas de Composición de Alimentos (Spanish Food Composition Tables). 5th ed. Universidad de Granada, Granada.
- Mazac, R., Renwick, K., Seed, B., Black, J.L., 2021. An approach for integrating and analyzing sustainability in food-based dietary guidelines. *Front. Sustain. Food Syst.* 5, 544072.
- Ministerio de Salud, Subsecretaría de Salud Pública, División de Políticas Públicas Saludables y Promoción, Departamento de Nutrición y Alimentos, 2022. Guías Alimentarias para Chile. Chile. [consulted 27 April 2023]. Available in: <https://www.minsal.cl/guias-alimentarias-para-chile/>.
- Ministry of Health of Brazil, 2015. Secretariat of Health Care, Primary Health Care Department. Dietary Guidelines for the Brazilian Population. Brazil. [consulted 27 April 2023]. Available in: http://189.28.128.100/dab/docs/portaldab/publicacoes/guia_alimentar_
- Molina, L., Sarmiento, M., Peñafiel, J., Donaire, D., Garcia-Aymerich, J., Gomez, M., et al., 2017. Validation of the Regicor short physical activity questionnaire for the adult population. *PLoS One* 12 (1), e0168148.
- Monteiro, C.A., Levy, R.B., Claro, R.M., de Castro, I.R., Cannon, G., 2011. Increasing consumption of ultra-processed foods and likely impact on human health: evidence from Brazil. *Public Health Nutr.* 14 (1), 5–13.
- Monteiro, C.A., Moubarac, J.C., Cannon, G., Ng, S.W., Popkin, B., 2013. Ultra-processed products are becoming dominant in the global food system. *Obes. Rev.* 14 (Suppl. 2), 21–28.
- Monteiro, C.A., Cannon, G., Moubarac, J.C., Martins, A.P., Martins, C.A., Garzillo, J., et al., 2015. Dietary guidelines to nourish humanity and the planet in the twenty-first century. A blueprint from Brazil. *Public Health Nutr.* 18 (13), 2311–2322.
- Monteiro, C.A., Cannon, G., Levy, R.B., Moubarac, J.C., Louzada, M.L., Rauber, F., et al., 2019a. Ultra-processed foods: what they are and how to identify them. *Public Health Nutr.* 22 (5), 936–941.
- Monteiro, C.A., Cannon, G., Lawrence, M., Costa Louzada, M.L., Pereira, Machado P., 2019b. Ultra-processed Foods, Diet Quality, and Health Using the NOVA Classification System. FAO, Rome [consulted 2 March 2022]. Available in: <https://www.fao.org/3/ca5644en/ca5644en.pdf> [consulted 2 March 2022]. Available in:
- Moreiras, O., Carbajal, A., Cabrera, L., Cuadrado, C., 2015. Tablas de composición de alimentos, guía de prácticas (Spanish Food Composition Tables). 17th ed. Pirámide, Madrid.
- Moubarac, J.C., Martins, A.P., Claro, R.M., Levy, R.B., Cannon, G., Monteiro, C.A., 2013. Consumption of ultra-processed foods and likely impact on human health. Evidence from Canada. *Public Health Nutr.* 16 (12), 2240–2248.
- Notarnicola, B., Tassielli, G., Renzulli, P.A., Castellani, V., Sala, S., 2017. Environmental impacts of food consumption in Europe. *J. Clean. Prod.* 140, 753–765.
- Pagliai, G., Dinu, M., Madarena, M.P., Naccio, M., Iacoviello, L., Sofi, F., 2021. Consumption of ultra-processed foods and health status: a systematic review and meta-analysis. *Br. J. Nutr.* 125 (3), 308–318.
- Popkin, B.M., Barquera, S., Corvalan, C., Hofman, K.J., Monteiro, C., Ng, S.W., et al., 2021. Towards unified and impactful policies to reduce ultra-processed food consumption and promote healthier eating. *Lancet Diabetes Endocrinol.* 9 (7), 462–470.
- Poti, J.M., Braga, B., Qin, B., 2017. Ultra-processed food intake and obesity: what really matters for health-processing or nutrient content? *Curr. Obes. Rep.* 6 (4), 420–431.
- Romaguera, D., Fernández-Barrés, S., Gracia-Lavedán, E., Vendrell, E., Azpiri, M., Ruiz-Moreno, E., et al., 2021. Consumption of ultra-processed foods and drinks and colorectal, breast, and prostate cancer. *Clin. Nutr.* 40 (4), 1537–1545.
- Schröder, H., Zomeño, M.D., Martínez-González, M.A., Salas-Salvadó, J., Corella, D., Vioque, J., et al., 2021. Validity of the energy-restricted Mediterranean Diet Adherence Screener. *Clin. Nutr.* 40 (8), 4971–4979.
- Serra-Majem, L., Tomaino, L., Dernini, S., Berry, E.M., Lairon, D., Ngo de la Cruz, J., Bach-Faig, A., Donini, L.M., Medina, F.X., Belahsen, R., Piscopo, S., Capone, R., Aranceta-Bartrina, J., La Vecchia, C., Trichopoulou, A., 2020. Updating the Mediterranean diet pyramid towards sustainability: focus on environmental concerns. *Int. J. Environ. Res. Public Health* 17 (23), 8758 Nov 25.
- Seves, S.M., Verkaik-Kloosterman, J., Biesbroek, S., Temme, E.H., 2017. Are more environmentally sustainable diets with less meat and dairy nutritionally adequate? *Public Health Nutr.* 20 (11), 2050–2062.
- da Silva, J.T., Garzillo, J.M.F., Rauber, F., Kluczkovski, A., Rivera, X.S., Lopes da Cruz, G., et al., 2021. Greenhouse gas emissions, water footprint, and ecological footprint of food purchases according to their degree of processing in Brazilian metropolitan areas: a time-series study from 1987 to 2018. *Lancet Planet. Health* 5 (11), e775–e785.
- Souza, T.N., Andrade, G.C., Rauber, F., Levy, R.B., da Costa Louzada, M.L., 2021. Consumption of ultra-processed foods and the eating location: can they be associated? *Br. J. Nutr.* 1–8.
- Talens, P., Cámara, M., Daschner, A., López, E., Marín, S., Martínez, J.A., et al., 2020. Informe del Comité Científico de la Agencia Española de Seguridad Alimentaria y Nutrición (AESAN) sobre el impacto del consumo de alimentos “ultra-procesados” en la salud de los consumidores. *Revista del Comité Científico de la AESAN* 31, 49–76.
- Tapsell, L.C., Neale, E.P., Satija, A., Hu, F.B., 2016. Foods, nutrients, and dietary patterns: interconnections and implications for dietary guidelines. *Adv. Nutr.* 7 (3), 445–454.
- The Nutrition Division, 2019. Nutritional Recommendations. The Israeli Ministry of Health. Ministry of Health, Israel 2019 [consulted 2 March 2022]. Available in: <https://www.health.gov.il/PublicationsFiles/dietary%20guidelines%20EN.pdf>.
- United Nations (UN), d. Sustainable development goals. Available from: <https://sdgs.un.org/es/goals> (accessed on November 19, 2021).
- Vellinga, R.E., van Bakel, M., Biesbroek, S., Toxopeus, I.B., de Valk, E., Hollander, A., et al., 2022. Evaluation of foods, drinks and diets in the Netherlands according to the degree of processing for nutritional quality, environmental impact and food costs. *BMC Public Health* 22 (1), 877.
- Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al., et al., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet.* 393 (10170), 447–492.