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Ultra-processed foods and human and planetary health

Edited by
Gustavo Cediel, Fernanda Rauber and Raquel Mendonça

Coordinated by
Maria Alvim Leite, Maria Gombi-Vaca and Adriana Meireles

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Ultra-processed foods and human and planetary health

Topic editors
Gustavo Cediel — University of Antioquia, Colombia
Fernanda Rauber — University of São Paulo, Brazil
Raquel Mendonça — Universidade Federal de Ouro Preto, Brazil

Topic Coordinators
Maria Alvim Leite — University of São Paulo, Brazil
Maria Gombi-Vaca — University of Connecticut, United States
Adriana Meireles — Universidade Federal de Ouro Preto, Brazil

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EDITED AND REVIEWED BY
Mauro Serafini,
University of Teramo, Italy

*CORRESPONDENCE
Fernanda Rauber
✉ rauber@usp.br

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Editorial: Ultra-processed foods and human and planetary health

Gustavo Cediel[1], Raquel de Deus Mendonça[2,3], Adriana Lúcia Meireles[2,3], Maria Alvim Leite[4,5], Maria F. Gombi-Vaca[5,6] and Fernanda Rauber[4,5]*

[1]School of Nutrition and Dietetics, University of Antioquia, Medellín, Colombia, [2]Department of Clinical and Social Nutrition, School of Nutrition, University of Ouro Preto, Ouro Preto, Brazil, [3]Research and Teaching Group in Nutrition and Public Health, Graduate Program in Health and Nutrition, Federal University of Ouro Preto, Ouro Preto, Brazil, [4]Department of Preventive Medicine, School of Medicine, University of São Paulo, São Paulo, Brazil, [5]Center for Epidemiological Research in Nutrition and Health, University of São Paulo, São Paulo, Brazil, [6]Rudd Center for Food Policy and Health, University of Connecticut, Hartford, CT, United States

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Editorial on the Research Topic
Ultra-processed foods and human and planetary health

In 2010, the Nova food classification system introduced the definition of "ultra-processed" as a food category, and it has been adopted as a system to categorize foods to better understand the role of ultra-processing of foods on human and planetary health. Since then, Nova has been used in scientific studies and has been referenced in documents and recommendations released by national governments, international organizations, and civil society.

Ultra-processed foods (UPF) are defined as industrial formulations made by deconstructing whole foods into food-derived substances (e.g., fats, sugars, starch, protein isolate), altering them, and recombining them with additives, like colors, flavors, and emulsifiers into products (1). Typical examples of UPF are soft drinks, fast foods, chicken nuggets, instant soups, fruit drinks, and flavored yogurts. UPF are made and sold by transnational food corporations, and are convenient, affordable, and hyper-palatable. These foods displace fresh and minimally processed foods and freshly prepared meals and have occupied a significant portion of the diet in various populations (2).

This current Research Topic describes the impact of UPF on health outcomes and inequalities, and validates, even more, UPF as an indicator in diet-related studies.

Five articles focused on the effect of UPF specifically on health-related outcomes. Rudakoff et al. investigated the association between UPF consumption and adiposity in young Brazilian adults. This study found an association between UPF consumption and increases in body mass index (BMI), body fat percentage, fat mass index, android and gynoid fat, and decreases in lean mass percentage. Ashraf et al. evaluated the degree of food processing and its association with anthropometric measures among Canadian families with preschool-aged children, and found that consumption of UPF was positively associated with BMI and waist circumference in adults and children. Nilson et al. estimated cardiovascular disease premature deaths and incident cases, and the disability adjusted life-years attributable to UPF consumption among Brazilian adults, and found that ∼22% of the premature deaths from cardiovascular disease and 33% of the total premature all cause deaths were attributable to UPF intake. Lopes et al. assessed the impact of food consumption, categorized by the degree of processing, on the serum fatty acid levels and lipid profiles of women with severe obesity. They observed an association between the consumption of processed and UPF and unfavorable lipid profiles and fatty acid levels among the participants. Finally, Coletro et al. described the association between co-occurrence of health risk behaviors (e.g., sedentarism, high frequency of UPF consumption, non-daily consumption of fruits and vegetables) and symptoms of anxiety and depression in adults. The study concluded that the combination of two and three health risk behaviors was associated with higher prevalence of the symptoms of anxiety or depression.

Two articles focused on consumption of UPF during pregnancy and in complementary feeding. Kelsey et al. described the association between UPF intake, diet quality, and dietary and inflammatory biomarkers among Norwegian women during mid-pregnancy. This study found that higher UPF intake was associated with reduced concentrations of nutrition biomarkers in mid-pregnancy. Moreira et al. conducted a randomized clinical trial to understand the association between different methods of food introduction (conventional technique/Parent-Led Weaning—PLW; Baby-Led Introduction to SolidS—BLISS); and mixed technique (both PLW and BLISS methods) and UPF consumption in early childhood. The study found that complementary feeding intervention focused on promoting infant autonomy (BLISS and mixed) was associated with reduction in the offer of UPF.

Two articles focused on the consumption of UPF and socioeconomic inequalities. Louzada et al. found that socioeconomic inequalities in food consumption decreased over a 10-year period in Brazil, but it may lead to the overall deterioration of the dietary quality for the more vulnerable populations. Crepaldi et al. examined the intersectionality of education, sex and race/skin color inequalities on consumption of unprocessed, minimally processed and UPF among Brazilians. The authors found that educational inequalities more strongly affected unprocessed/minimally processed food consumption than UPF. They also noted greater UPF inequalities among black/brown men and women than among white men.

Finally, there were two studies focused on validation of the Nova system included in this Research Topic. Huybrechts et al. used Nova classification to compare diets across the cultural and socio-economic diversity of European populations and validated it against biomarker measurements. Based on a large pan-European cohort, it demonstrated sociodemographic and geographical differences in the consumption of UPF. Furthermore, the results suggest that Nova classification can accurately capture UPF consumption, reflected by stronger correlations with food processing biomarkers (i.e., plasma elaidic acid, an unsaturated trans-fatty acid, and urinary 4-methylsyringol sulfate). Zancheta Ricardo et al. compared the frequency of UPF and their dietary share among the diet of Chilean preschoolers applying three distinct methods to identify UPF. The study found that searching for all possible markers of UPF in the list of ingredients increased the proportion of food products identified as UPF when compared to a classic method of food classification.

While this Research Topic did not yield published manuscripts specifically addressing the environmental impact of UPF, we strongly urge researchers to delve into this crucial aspect. UPF are typically associated with large-scale food production, which is often environmentally unsustainable. In the healthy and sustainability perspective, food extends beyond its mere nutritional components, encompassing a broader perspective that values health, supportiveness and sustainability. On one hand, this perspective promotes the adoption of dietary patterns based on natural foods, acquired through cooperative socio-environmental models that align with nature conservation and the unique culinary traditions of each region. On the other hand, it discourages dietary patterns associated with the corporate food industry, characterized by mass production of UPF. Such patterns have been associated with various forms of malnutrition and chronic diseases. Additionally, they are often entwined with marketing practices that tend to be socially unfair and environmentally unsustainable (3, 4). By centering our focus toward promoting more sustainable whole food options we will contribute to improve human health and to a more balanced relationship with our planet.

Author contributions

GC: Writing—original draft. RM: Writing—review and editing. AM: Writing—review and editing. ML: Writing—review and editing. MG-V: Writing—review and editing. FR: Writing—review and editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Fernanda Rauber,
University of São Paulo, Brazil

REVIEWED BY
Ariene Carmo,
Minas Gerais State University, Brazil
Manon Cairat,
International Agency for Research on Cancer (IARC), France

*CORRESPONDENCE
David W. L. Ma
davidma@uoguelph.ca

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The degree of food processing is associated with anthropometric measures of obesity in Canadian families with preschool-aged children

Rahbika Ashraf[1], Alison M. Duncan[1], Gerarda Darlington[2], Andrea C. Buchholz[3], Jess Haines[3] and David W. L. Ma[1]* on behalf of the Guelph Family Health Study

[1]Department of Human Health and Nutritional Sciences, University of Guelph, Guelph, ON, Canada,
[2]Department of Mathematics and Statistics, University of Guelph, Guelph, ON, Canada,
[3]Department of Family Relations and Applied Nutrition, University of Guelph, Guelph, ON, Canada

Adopting a healthy diet remains central for the prevention of obesity. In adults, higher intake of ultra-processed food is associated with a greater risk of overweight and obesity. However, little is known about the degree of food processing and its association with anthropometric measures in families with preschool-aged children, a critical period for the development of dietary patterns. This cross-sectional study included preschool-aged children (n = 267) between 1.5 and 5 years of age and their parents (n = 365) from 242 families enrolled in the Guelph Family Health Study. Dietary assessment was completed using ASA24-Canada-2016. Foods and beverages were classified based on their degree of food processing using the NOVA Classification (unprocessed or minimally processed foods, processed culinary ingredients, processed foods, and ultra-processed foods). Associations between the energy contribution (% kcal) of each NOVA category and anthropometric measures were examined using linear regression models with generalized estimating equations, adjusted for sociodemographic variables. The energy contribution of ultra-processed foods was the highest relative to the other NOVA categories among parents (44.3%) and children (41.3%). The energy contribution of unprocessed or minimally processed foods was 29.1% for parents and 35.3% for children, processed foods was 24.0% for parents and 21.3% for children, and processed culinary ingredients was 2.6% for parents and 2.1% for children. Ultra-processed foods (% kcal) were positively associated with BMI (β = 0.04, 95% CI: 0.01–0.07, P = 0.02), waist circumference (β = 0.11, 95% CI: 0.03–0.18, P = 0.008) and body weight (β = 0.13, 95% CI: 0.03–0.22, P = 0.01) in parents, but not children. Unprocessed foods (% kcal) were negatively associated with waist circumference in parents (β = −0.09, 95% CI: 0.18–0.01, P = 0.03) and children (β = −0.03, 95% CI: 0.05–0.01, P = 0.01), as well as body weight (β = −0.12, 95% CI: 0.23–0.00, $P = 0.04$) in parents. The degree of food processing primarily influenced anthropometric outcomes in parents. Nevertheless, diets of children were similar, suggesting that such exposure in families may eventually lead to outcomes observed in parents.

KEYWORDS

ultra-processed foods, NOVA food classification system, obesity, BMI, ASA24, children, health, disease prevention

Introduction

Obesity is a public health problem and the increased prevalence of obesity worldwide is driven in part by changes in the global food system, replacing dietary patterns based on home-prepared foods with industrially processed and pre-packaged foods (1). Evidence suggests that a greater intake of ultra-processed foods is associated with obesity and related cardiometabolic outcomes (2, 3). Ultra-processed foods are defined by the NOVA food classification system as industrial formulations of ingredients derived from additives and food substances (4). The NOVA system is a diet classification tool that considers the nature, purpose and extent of food processing when classifying foods and beverages into four categories that range from least to most processed and include: unprocessed or minimally processed foods (e.g., whole foods, fruits, vegetables, eggs, and milk); processed culinary ingredients (e.g., sugar, salt, butter, and cooking oil); processed foods (e.g., salted nuts, simple breads, and cheese); ultra-processed foods (e.g., pre-packaged meals and breads, sugary drinks and sweetened or salty snacks) (4). Ultra-processed foods are typically energy-dense and characterized as having poor nutritional content, including higher levels of sodium, free and added sugars and saturated fats, compared to their unprocessed or minimally processed counterparts (4).

Data from household food purchases reveal an increase in ultra-processed food sales globally (5). This rise in household availability of ultra-processed foods parallels the increased prevalence of overweight and obesity (5, 6). Clinical and observational studies have also identified a potential association between ultra-processed food consumption and increased obesity risk. For example, results of a randomized controlled trial demonstrated that an ultra-processed diet caused weight gain in adults relative to an unprocessed diet despite being matched for calories (7). Cross-sectional studies reported similar findings linking higher intakes of ultra-processed foods to increased prevalence of obesity in both adults and children (8–12). Similar associations between ultra-processed food intakes and anthropometric measures or related risk markers have been identified in longitudinal studies in adults (13–17) and children (18–20). Recent systematic reviews and meta-analyses also confirm the overarching finding that ultra-processed foods are positively associated with excess body weight and obesity in adolescents and adults (21, 22) and additional factors related to cardiometabolic risk in children and adults (23). However, the role of the different degrees of food processing (ranging from unprocessed to ultra-processed) on indicators of obesity in children remains unknown.

Further, although children are the leading consumers of ultra-processed foods (24–26), few studies have explored the association between the degree of food processing and obesity risk in preschool-aged children. The focus on young children is important as early dietary behaviors may track into adulthood, potentially playing a role in the development of chronic diseases later in life (27). The home food environment also influences the development of early dietary patterns, underscoring the importance of research within the family unit (27–29). Thus, assessing dietary intake in families, including both parents and children may provide unique perspectives of the role of the family environment in shaping children's food choices and dietary habits. Since the most effective programs for addressing and preventing childhood obesity are family based, insights into the dietary intakes of parents and children may provide the basis of future diet and weight-related behavior change interventions (30). Therefore, the aim of this study was to investigate the associations between food intake according to the degree of food processing and anthropometric indicators of obesity in Canadian preschool-aged children and their parents.

Materials and methods

Study design and participants

The Guelph Family Health Study (GFHS) is a longitudinal health promotion study investigating early life risk factors for obesity and chronic diseases in families with young children. This cross-sectional study collected data from families participating in the GFHS between April 2017 and March 2020. Families were recruited through the local Family Health Team, Community Health Centre, and Ontario Early Years Centres if they had at least one child between the ages 1.5–5 years, resided in Guelph-Wellington in Ontario, Canada with no plans of relocating within next year, and could respond to questionnaires in English. Parents provided written informed consent and the University of Guelph Research Ethics Board approved the study (REB #17-07-003).

A total of 246 families (749 participants; 427 parents, 322 children) were enrolled in the GFHS. Of these, 117 participants were excluded from the current analyses due to the following: missing dietary data (37 parents, 28 children), implausible energy intakes (>1.5 times the interquartile range below the 25th or above the 75th percentiles; nine parents, 17 children), pregnancy or breastfeeding (16 mothers), breastfed (nine children), as intake amounts could not be verified, and illness (one child). The final sample for this study included n = 365 parents and n = 267 children from 242 families.

Dietary assessment

Parents reported dietary intake for themselves and parent 1 (defined as the first parent enrolled in the study, 90% mothers) reported dietary intake on behalf of their participating child(ren). Dietary intake data was evaluated for energy intakes using the National Cancer Institute's Automated Self-Administered 24-h (ASA24) Dietary Assessment Tool, version 2016 adapted for use in the Canadian population. The ASA24 is a self-administered, web-based 24-h dietary recall program that has been validated for use among adults (31) and preschool-aged children (32). The ASA24 was derived from the USDA's Automated Multiple-Pass Method (AMPM), providing a modified approach to traditional interviewer-administered 24-h recalls. The ASA24 uses food images to assist respondents with portion size estimation and provides nutrient content for foods, beverages, and supplements.

Classification of foods by the degree of processing

Foods reported in the 24-h recall were manually classified according to the degree of processing according to the four NOVA classification system categories: unprocessed or minimally processed foods, including naturally present "fresh" or "whole" foods altered by methods that do not require the addition of substances such as salts, sugars, oils or fats (e.g., fresh, frozen or dry fruits and vegetables, packaged grains, legumes, fresh or frozen meat and fish, eggs and plain milk); processed culinary ingredients, found in home kitchens to cook/season foods and make dishes palatable (e.g., starch, table sugar, salt, lard, butter, and oils); processed foods, described as products made by adding processed culinary ingredients such as salt, sugars and/or oils to unprocessed or minimally processed foods (e.g., artisan breads and cheeses, canned fish, salted meat, fruit preserves and vegetables in brine); ultra-processed foods, defined as ready-to-eat food products made with industrial formulations of ingredients and additives, containing minimal or no whole foods (e.g., soft drinks, sweetened or salted pre-packaged snacks, sweetened breakfast cereals, mass-produced breads, processed meats and ready-to-eat frozen or shelf-stable meals) (4, 33, 34). This work was completed by one trained researcher using a pre-constructed standard operating procedure that was independently reviewed by multiple researchers.

Automated Self-Administered 24-h "Food Description" and "Food Source" variables were used to identify the degree of food processing by providing information about the preservation processes (e.g., fresh, frozen, dried or canned in own juice, oil, water or syrup), production methods (e.g., home, bakery, or industrially prepared), addition of ingredients (e.g., sweetened, salted, or unsalted) and source of foods (e.g., fast food or grocery store). In cases of ambiguity, food items were coded under the lesser processed category. Zero-calorie foods (e.g., water) were not classified and excluded from the analyses. Since the reporting of recipes was not required in ASA24, home-made mixed dishes were classified as "un-disaggregated home-made dish" under the unprocessed or processed foods categories, depending on the processing level of the core ingredients (35). Energy intake from foods was quantified and reported in either absolute (kcal/day) and/or relative values (% kcal/day).

Anthropometric indicators of obesity

Anthropometric measures, including body weight, height and waist circumference were obtained at the University of Guelph Body Composition Laboratory. The measurements were performed by trained research staff and under standard conditions, with participants standing and either barefoot or in socks. Body weight (kg) was measured to the nearest 0.001 kg using a calibrated electronic weighing scale (BOD POD™, COSMED USA Inc., Concord, CA, USA). Height (cm) was measured to the nearest 0.1 cm using a calibrated wall-mounted stadiometer (Seca Model 222, Mount Pleasant, SC, USA) for parents and older children or a ShorrBoard pediatric measuring board (ShorrBoard®, Weigh and Measure LLC., Olney, MD, USA) for younger children. Waist circumference (cm) was measured to the nearest 0.1 cm at the top of the right iliac crest using a Gulick II measuring tape (Gulick II, Country Technology Inc., Gay Mills, WI, USA). Two measures were taken for height and waist circumference; if the difference between the values was greater than 0.5 cm, a third measure was taken and the mean of the nearest two values was reported as the final value. BMI [weight (kg)/height (m)^2] was calculated for the parents. BMI z-scores, measures of relative weight adjusted for child age and sex, were calculated for children based on the WHO Child Growth Standards using the R package "zscorer" version 0.3.1 statistical software (36).

Percent fat mass was measured by trained research staff using the BOD POD™ digital scale (COSMED USA Inc., Concord, CA, USA) for parents or during bioelectrical impedance analysis (BIA) using a Quantum IV BIA Analyzer System (RJL Systems, Clinton Township, MI, USA) for children. Participants were instructed to avoid food and drink and vigorous physical activity for 2 h (parents) or 30 min (children) prior to the assessment. Two BIA measurements were taken; if the difference between the two resistance values was greater than 5%, a third measurement was taken. Percent fat mass from the BIA assessment for children was estimated using total body water calculation by Kushner et al. (37) and hydration constants by Fomon et al. (38).

BMI or BMI z-scores for 36 participants (n = 11 parents and n = 25 children), waist circumference data for 38 participants (n = 8 parents and n = 30 children), body weight for 16 participants (n = 11 parents and n = 4 children) and percent fat mass data for 205 participants (n = 141 parents and n = 64 children) were missing and excluded from the regression analyses.

Statistical analysis

Data were analyzed using SAS University Edition version 3.6 (SAS Institute Inc., Cary, NC, USA) (39). Linear regression models with generalized estimating equations were fitted to estimate the associations between food intake according to the degree of food processing and obesity indicators (BMI or BMI z-scores, waist circumference, body weight and percent fat mass). Generalized estimating equations were used to obtain coefficient estimates (β), 95% confidence intervals (CIs), and P-values that account for dependence among participants within the same family (40). Anthropometric measures (BMI or BMI z-scores, waist circumference, body weight and percent fat mass) of parents and children were independently regressed onto each processed food category, expressed as percent of total energy. Analyses were conducted separately for parents and children. Models were adjusted for variables that were identified as potential confounders including age (years), sex, annual household income (<$50,000; $50,000–$99,999; $100,000–$149,999; $150,000 or more; Did not disclose), ethnicity (White; Other, including Black, Chinese, Japanese, Korean, Latin American, Mixed ethnicity, South Asian, Southeast Asian, and West Asian; or Did not disclose) and education for parent models (no postsecondary degree; postsecondary graduate; postgraduate training), or highest level of parental education for child models.

Results

Participant characteristics and energy intake

Participant characteristics are reported in **Table 1**. Among the total sample of 365 parents and 267 children, 59% were mothers (n = 216) and 52% were girls (n = 138). The mean age was 35.7 (SD = 4.7) years among parents and 3.6 (SD = 1.2) years among children. Approximately 80% of parents and 75% of children identified as White. A total of 49% of parents (n = 179) reported an annual household income of $100,000 or greater and about 35% (n = 127) obtained postgraduate training or degrees. The mean BMI or BMI z-score value for parents and children was 26.8 (SD = 6.1) and 0.5 (SD = 0.8), respectively. The mean waist circumference was 92.8 (SD = 15.1) for parents and 51.1 (SD = 3.3) for children. The mean percent fat mass values were 29.4 for both parents (SD = 9.9) and children (SD = 5.5). The mean daily energy intake was 2211.9 (SD = 859.5) kcal for parents and 1408.9 (SD = 381.2) kcal for children.

Distribution of energy intakes according to the degree of food processing

The dietary contribution of ultra-processed foods to total energy intake was the highest among the processed food categories, for both parents and children (**Table 2**). Ultraprocessed foods represented 44.3 and 41.3% of total energy intake among parents and children, respectively. Collectively, ready-to-eat meals, breads, and sweet desserts and baked goods accounted for almost half (20.6% of 44.3%) of the energy from ultra-processed foods in the parents' diets. Breads (6.7%), sweet snacks (5.6%), and sweetened milk-based products (5.3%) were the greatest contributors of energy from ultra-processed foods in the children's diets.

Unprocessed or minimally processed foods represented 29.1% of total energy intake in parents' diets and 35.3% in the children's diets. Home-made dishes (6.8%) and fruit and freshly squeezed fruit juices (5.2%) in the parents' diets, and fruit and freshly squeezed fruit juices (9.5%) and milk and plain yogurt (8.9%) in the children's diets provided the greatest energy from unprocessed or minimally processed foods.

Processed foods provided 24.0 and 21.3% of total energy in the parents' and children's diets, respectively, with processed home-made dishes contributing the greatest source of energy for both parents (10.6%) and children (8.6%).

Processed culinary ingredients accounted for 2.6% of energy intake in the parents' diets and 2.1% of energy intake in the children's diets. Animal fats (1.2%) and sugars (1.1%) were the main contributors of processed culinary ingredients in the diets of parents and children, respectively.

Associations between the degree of food processing and anthropometric indicators of obesity

For parents, ultra-processed foods (% kcal) were positively associated with BMI (β = 0.04, 95% CI: 0.01–0.07, P = 0.02),

TABLE 1 Participant characteristics of the Guelph Family Health Study, by age group and sex.

Characteristic	Mothers n = 216	Fathers n = 149	Parents overall n = 365	Girls n = 138	Boys n = 129	Children overall n = 267
Age (years), mean ± SD	35.1 ± 4.6	36.4 ± 4.8	35.7 ± 4.7	3.5 ± 1.2	3.6 ± 1.3	3.6 ± 1.2
BMI (kg/m^2), mean ± SD, n	26.8 ± 6.6, 212	27 ± 5.3, 142	26.8 ± 6.1, 354	0.5 ± 0.8, 127[1]	0.5 ± 0.8, 115[1]	0.5 ± 0.8, 242[1]
Waist Circumference (cm), mean ± SD, n	90.6 ± 15.6, 213	96.1 ± 13.9, 144	92.8 ± 15.1, 357	51.1 ± 3.4, 127	51.1 ± 3.2, 110	51.1 ± 3.3, 237
Body weight (kg), mean ± SD, n	72.7 ± 17.6, 212	86.9 ± 17.6, 142	78.4 ± 18.9, 354	15.4 ± 2.9, 136	16.1 ± 3.2, 127	15.8 ± 3.0, 263
Fat mass (%), mean ± SD, n	32.5 ± 9.2, 142	24.2 ± 8.9, 82	29.4 ± 9.9, 224	31.2 ± 5.5, 115	26.9 ± 4.6, 88	29.4 ± 5.5, 203
Ethnicity, n (%)						
White	177 (81.9)	117 (78.5)	294 (80.5)	106 (76.8)	95 (73.6)	201 (75.3)
Other[2]	39 (18.1)	32 (21.5)	71 (19.5)	32 (23.2)	34 (26.4)	66 (24.7)
Annual Household Income, n (%)						
Did not disclose or <$50,000	40 (18.5)	26 (17.5)	66 (18.1)	23 (16.7)	24 (18.6)	47 (17.6)
$50,000 to $99,999	73 (33.8)	47 (31.5)	120 (32.9)	43 (31.2)	35 (27.1)	78 (29.2)
$100,000 or more	103 (47.7)	76 (51)	179 (49.1)	72 (52.2)	70 (54.2)	142 (53.2)
Education, n (%)						
No postsecondary degree	21 (9.7)	36 (24.2)	57 (15.6)	–	–	–
University or college graduate	107 (49.5)	74 (49.7)	181 (49.6)	–	–	–
Postgraduate training or degree	88 (40.7)	39 (26.2)	127 (34.8)	–	–	–
Energy Intake (kcal), mean ± SD	2007.3 ± 712.6	2508.6 ± 964.1	2211.9 ± 859.5	1369.4 ± 373.0	1451.2 ± 386.8	1408.9 ± 381.2

The total sample of participants from the GFHS included in this study was n = 365 parents and n = 267 children from 242 families. Missing BMI or BMI z-score data for 36 participants (11 parents and 25 children), waist circumference data for 38 participants (8 parents and 30 children), body weight data for 16 participants (n = 11 parents and n = 4 children) and fat mass (%) data for 205 participants (n = 141 parents and n = 64 children).

[1]BMI z-score, calculated per World Health Organization Child Growth Standards, adjusted for age and sex.

[2]Black, Chinese, Japanese, Korean, Latin American, Mixed ethnicity, South Asian, Southeast Asian, and West Asian or did not disclose.

waist circumference (β = 0.11, 95% CI: 0.03–0.18, P = 0.008) and body weight (β = 0.13, 95% CI: 0.03–0.22, P = 0.01), with a borderline result seen for percent fat mass (β = 0.05, 95% CI: 0.00–0.11, P = 0.054) (Table 3). No significant associations were seen between ultra-processed food intake and anthropometric measures in children (Table 4). However, processed foods (%) were positively associated with BMI z-scores (β = 0.008, 95% CI: 0.001–0.015, P = 0.04) in children, but not BMI in parents. In contrast, unprocessed or minimally processed foods (% kcal) were negatively associated with waist circumference in parents (β = −0.09, 95% CI: 0.18–0.01, P = 0.03) and children (β = −0.03, 95% CI: 0.05–0.01, P = 0.01). Unprocessed or minimally processed foods (% kcal) were also negatively associated with body weight in parents (β = −0.12, 95% CI: 0.23–0.00, P = 0.04). No additional significant associations between processed foods or processed culinary ingredients and anthropometric measures were seen in parents or children.

Discussion

This cross-sectional study examined associations between the degree of food processing and anthropometric measures of obesity among a sample of Canadian families with young children. The results of this study showed that ultra-processed foods accounted for a greater proportion of energy intake relative to the other less processed food categories among both parents (44%) and preschoolers (41%). Ultra-processed food intake was positively associated with a small but significant increase in BMI, waist circumference, and body weight, as well as a marginally significant increase in percent body fat in parents, but not children. Unprocessed or minimally processed foods were inversely associated with waist circumference in both parents and children, and body weight in parents only. Processed foods were positively associated with BMI z-scores in children, but no further associations with anthropometric measures were noted in parents or children.

The findings of this current study are consistent with existing research highlighting a associations between excess ultra-processed food consumption and weight gain, and conversely, unprocessed food consumption and weight loss, in adults (7). In a recent randomized controlled trial, Hall et al. (7) found that inpatients who consumed an ultra-processed diet for 2 weeks gained 0.9 ± 0.3 kg and had higher *ad libitum* energy intake relative to an unprocessed diet, whereas patients lost, on average 0.9 ± 0.3 kg while consuming an unprocessed diet. In support of our results, cross-sectional associations between ultra-processed food intake and obesity have been reported among adults from the USA (41), Canada (42), Australia (10), and Brazil (43). Findings from recent prospective studies also revealed that greater ultra-processed food intake was associated with increased incidence of obesity or weight gain among Brazilian (14), UK (13), Spanish (15), and French adults (16), as well as increased visceral fat deposition in overweight or obese older adults (aged 55–75 years old) with metabolic syndrome (17). Along with a greater risk of obesity, greater ultra-processed

TABLE 2 Distribution of energy intake among NOVA food classification categories among participants in the Guelph Family Health Study (n = 365 parents and n = 267 children from 242 families).

NOVA food classification category	Parent's energy intake		Children's energy intake	
	Mean ± SD (kcal/day)	% Total kcal	Mean ± SD (kcal/day)	% Total kcal
Unprocessed or minimally processed foods[1]	**643.3 ± 404.6**	**29.1**	**497.9 ± 268.3**	**35.3**
Meat and poultry	86.0 ± 166.3	3.9	33.8 ± 85.7	2.4
Grains and flours	49.0 ± 106.2	2.2	33.6 ± 72.7	2.4
Fruit and freshly squeezed fruit juices	114.9 ± 121.3	5.2	133.3 ± 101.1	9.5
Milk and plain yogurt	54.4 ± 88.8	2.5	125.8 ± 134.6	8.9
Pasta	64.0 ± 175.3	2.9	45.0 ± 106.2	3.2
Vegetables	24.8 ± 42.0	1.1	12.1 ± 20.2	0.9
Eggs	19.1 ± 50.1	0.9	6.8 ± 23.0	0.5
Roots and tubers	11.0 ± 43.7	0.5	6.1 ± 17.0	0.4
Nuts and seeds	44.4 ± 115.6	2.0	9.8 ± 41.6	0.7
Fish and seafood	4.8 ± 31.9	0.2	3.6 ± 26.9	0.3
Legumes	14.4 ± 65.6	0.7	7.9 ± 26.9	0.6
Un-disaggregated home-made dishes[2]	149.6 ± 190.8	6.8	79.3 ± 134.5	5.6
Other unprocessed/minimally processed foods[3]	6.9 ± 27.2	0.3	0.9 ± 8.7	0.1
Processed culinary ingredients[4]	**57.3 ± 114.6**	**2.6**	**29.4 ± 49.4**	**2.1**
Plant oils	8.4 ± 67.1	0.4	1.6 ± 8.2	0.1
Sugars[5]	19.8 ± 41.1	0.9	15.8 ± 35.7	1.1
Animal fats	26.8 ± 65.5	1.2	11.7 ± 31.4	0.8
Other processed culinary ingredients[6]	2.3 ± 30.2	0.1	0.4 ± 6.3	0.03
Processed foods[7]	**531.9 ± 492.1**	**24.0**	**299.6 ± 225.4**	**21.3**
Cheese	103.3 ± 182.1	4.7	88.1 ± 126.3	6.3
Canned fruit, vegetables, other plant foods	4.0 ± 18.2	0.2	6.1 ± 20.7	0.4
Salted, smoked or canned meat or fish	31.3 ± 87.8	1.4	7.3 ± 38.2	0.5
Un-disaggregated home-made dishes[8]	233.7 ± 332.8	10.6	121.4 ± 182.6	8.6
Other processed foods[9]	159.5 ± 254.3	7.2	76.8 ± 115.1	5.4
Ultra-processed foods[10]	**979.4 ± 662.6**	**44.3**	**581.9 ± 308.1**	**41.3**
Pre-prepared/ready-to-eat and frozen dishes[11]	202.0 ± 398.8	9.1	53.5 ± 131.5	3.8
French fries and other potato products[12]	31.2 ± 102.6	1.4	16.0 ± 53.1	1.1
Breads	146.5 ± 212.7	6.6	93.8 ± 100.4	6.7
Soft drinks and sweetened fruit juices and drinks	38.0 ± 87.3	1.7	9.9 ± 35.5	0.7
Sweetened milk-based products[13]	66.9 ± 129.0	3.0	75.1 ± 103.0	5.3
Sweet snacks	89.6 ± 161.9	4.1	79.5 ± 109.9	5.6
Sweet desserts and baked goods	109.4 ± 233.4	4.9	51.8 ± 96.1	3.7
Sauces and spreads	84.5 ± 124.3	3.8	41.6 ± 75.6	3.0
Salty snacks	59.4 ± 120.4	2.7	51.7 ± 84.3	3.7
Reconstituted meat or fish products[14]	34.9 ± 90.7	1.6	29.6 ± 76.9	2.1
Sweetened breakfast cereals	37.0 ± 99.8	1.7	29.4 ± 58.5	2.1
Other ultra-processed foods[15]	80.2 ± 188.6	3.6	50.0 ± 106.9	3.5
Total	**2211.9 ± 859.5**	**100.0**	**1408.9 ± 381.2**	**100.0**

The total sample of participants from the GFHS included in this study was n = 365 parents and n = 267 children from 242 families.

[1]Unprocessed and minimally processed foods defined as naturally occurring, whole and fresh foods that undergo no or minimal industrial processing typically to preserve foods and improve palatability. Examples include vegetables, fruits, nuts, eggs, meat and milk.

[2]Made with no processed foods, but contain PCI (salts, sugars, and fats); homemade soup, omelet and baked potato.

[3]Coffee (non−presweetened, non-whitened, and non-flavored), tea (non−presweetened, non-whitened, and non-flavored), yeast, dried fruits (without added sugars) and vegetables.

[4]Processed culinary ingredients defined as substances that are used in preparation of foods to enhance flavor of meals. Examples include sugars, butter, oils, and salt.

[5]White and brown sugar, iced sugar, molasses, honey, maple syrup (100%).

[6]Vinegar, corn starch.

[7]Processed foods defined as foods that undergo some processing by combining minimally processed or unprocessed foods and processed culinary ingredients and often require minimal preparation. Examples include simple breads, cheese, salted nuts, and canned meat.

[8]Homemade mixed dishes that are not classifiable in any of the other categories. Made from adding PCI to PFs; home-made pizza with cheese, home-made lasagna.

[9]Salted, sweetened or oil roasted nuts or seeds, prepared tofu, and dried sweetened fruits (raisin).

[10]Ultra-processed foods defined as convenient foods that are a result of industrial formulations typically with five or more ingredients plus additives. Examples include Sugary drinks, chips, sweetened milk products, cereals, flavored yogurts and packaged desserts.

[11]Frozen dishes, burgers, pizzas, sandwiches and other pre-prepared products bought in fast-food outlets.

[12]Ready-to-eat and frozen French fries, onion rings, hash browns, mash potatoes and other potato products.

[13]Ice cream, chocolate milk, flavored yogurt, milkshakes.

[14]Sausages, deli-meats, meat spreads, mass-produced bacon, fish sticks.

[15]Canned soups, canned mixed dishes, cheese products, fish or seafood imitations, meal replacements, sweeteners, protein shake powder, egg substitutes, coffee whitener, meatless burgers and sausages, other sugared beverages, soy products (meatless patties, soymilk etc.).

TABLE 3 Association between the intakes of the NOVA food classification categories and anthropometric indicators of obesity[1,2] among parents (n = 365 participants from 242 families).

NOVA category (% total energy intake)	BMI (kg/m^2)	Waist circumference (cm)	Body weight (kg)	Fat mass (%)
	(n = 354)	(n = 357)	(n = 354)	(n = 224)
Unprocessed or minimally processed foods[3] β (95% CI) *P*-value	−0.03 (−0.07, 0.01) *P* = 0.09	−0.09 (−0.18, −0.01) *P* = 0.03	−0.12 (−0.23, 0.00) *P* = 0.04	−0.06 (−0.13, 0.01) *P* = 0.07
Processed culinary ingredients[4] β (95% CI) *P*-value	−0.08 (−0.18, 0.02) *P* = 0.13	0.04 (−0.40, 0.48) *P* = 0.87	−0.18 (−0.51, 0.15) *P* = 0.29	−0.16 (−0.40, 0.08) *P* = 0.20
Processed foods[5] β (95% CI) *P*-value	−0.02 (−0.05, 0.02) *P* = 0.36	−0.06 (−0.15, 0.03) *P* = 0.19	−0.05 (−0.15, 0.06) *P* = 0.39	−0.01 (−0.08, 0.06) *P* = 0.83
Ultra-processed foods[6] β (95% CI) *P*-value	0.04 (0.01, 0.07) *P* = 0.02	0.11 (0.03, 0.18) *P* = 0.008	0.13 (0.03, 0.22) *P* = 0.01	0.05 (0.00, 0.11) *P* = 0.054

The total sample of parents from the GFHS included in this study was n = 365. BMI z-score for 11 participants, waist circumference for eight participants, body weight for 11 participants and fat mass (%) data for 141 participants were missing and excluded from regression analyses.
[1]Results presented as linear regression coefficients (β) using generalized estimating equations with 95% confidence intervals (CI) and *P*-values.
[2]Models adjusted for age (years), sex, annual household income (<\$50,000; \$50,000–\$99,999; \$100,000–\$149,999; \$150,000 or more; Did not disclose), ethnicity [White; Other (including Black, Chinese, Japanese, Korean, Latin American, Mixed ethnicity, South Asian, Southeast Asian, and West Asian) or Did not disclose] and parental education for parent models (no postsecondary degree; postsecondary graduate; postgraduate training), or highest level of parental education for child models.
[3]Unprocessed and minimally processed foods defined as naturally occurring, whole and fresh foods that undergo no or minimal industrial processing typically to preserve foods and improve palatability. Examples include vegetables, fruits, nuts, eggs, meat, and milk.
[4]Processed culinary ingredients defined as substances that are used in preparation of foods to enhance flavor of meals. Examples include sugars, butter, oils, and salt.
[5]Processed foods defined as foods that undergo some processing by combining minimally processed or unprocessed foods and processed culinary ingredients and often require minimal preparation. Examples include simple breads, cheese, salted nuts, and canned meat.
[6]Ultra-processed foods defined as convenient foods that are a result of industrial formulations typically with five or more ingredients plus additives. Examples include Sugary drinks, chips, sweetened milk products, cereals, flavored yogurts, and packaged dessert.

TABLE 4 Association between the intakes of the NOVA food classification categories and anthropometric indicators of obesity[1,2] among preschool-aged children (n = 267 participants from 242 families).

NOVA category (% total energy intake)	BMI Z-scores[3]	Waist circumference (cm)	Body weight (kg)	Fat mass (%)
	(n = 242)	(n = 237)	(n = 263)	(n = 203)
Unprocessed or minimally processed foods[4] β (95% CI) *P*-value	−0.004 (−0.011, 0.002) *P* = 0.17	−0.03 (−0.05, −0.01) *P* = 0.01	−0.009 (−0.021, 0.003) *P* = 0.15	−0.03 (−0.07, 0.01) *P* = 0.15
Processed culinary ingredients[5] β (95% CI) *P*-value	0.01 (−0.02, 0.04) *P* = 0.47	0.06 (−0.05, 0.16) *P* = 0.28	0.05 (0.00, 0.10) *P* = 0.07	−0.04 (−0.21, 0.13) *P* = 0.67
Processed foods[6] β (95% CI) *P*-value	0.008 (0.001, 0.015) *P* = 0.04	0.01 (−0.02, 0.04) *P* = 0.56	0.009 (−0.007, 0.025) *P* = 0.27	0.02 (−0.02, 0.07) *P* = 0.32
Ultra-processed foods[7] β (95% CI) *P*-value	−0.002 (−0.008, 0.004) *P* = 0.51	0.013 (−0.007, 0.033) *P* = 0.21	−0.001 (−0.01, 0.01) *P* = 0.92	0.01 (−0.03, 0.05) *P* = 0.59

The total sample of children from the GFHS included in this study was n = 267. BMI z-score for 25 participants, waist circumference for 30 participants, body weight for four participants and fat mass (%) data for 64 participants were missing and excluded from regression analyses.
[1]Results presented as linear regression coefficients (β) using generalized estimating equations with 95% confidence intervals (CI) and *P*-values.
[2]Models adjusted for age (years), sex, annual household income (<\$50,000; \$50,000–\$99,999; \$100,000–\$149,999; \$150,000 or more; Did not disclose), ethnicity [White; Other (including Black, Chinese, Japanese, Korean, Latin American, Mixed ethnicity, South Asian, Southeast Asian, and West Asian) or Did not disclose] and parental education for parent models (no postsecondary degree; postsecondary graduate; postgraduate training), or highest level of parental education for child models.
[3]BMI z-score, calculated per World Health Organization Child Growth Standards, adjusted for age and sex.
[4]Unprocessed and minimally processed foods defined as naturally occurring, whole and fresh foods that undergo no or minimal industrial processing typically to preserve foods and improve palatability. Examples include vegetables, fruits, nuts, eggs, meat, and milk.
[5]Processed culinary ingredients defined as substances that are used in preparation of foods to enhance flavor of meals. Examples include sugars, butter, oils, and salt.
[6]Processed foods defined as foods that undergo some processing by combining minimally processed or unprocessed foods and processed culinary ingredients and often require minimal preparation. Examples include simple breads, cheese, salted nuts, and canned meat.
[7]Ultra-processed foods defined as convenient foods that are a result of industrial formulations typically with five or more ingredients plus additives. Examples include Sugary drinks, chips, sweetened milk products, cereals, flavored yogurts, and packaged dessert.

food intake has been associated with an increased risk of all-cause mortality and other diet-related non-communicable diseases including type 2 diabetes, hypertension and cancer (7, 44, 45). Conversely, a diet high in unprocessed or minimally processed foods (e.g., fruits, vegetables, nuts, seeds, whole grains, and fish) has been observed to have a protective effect on cardiometabolic health (46). Therefore, decreasing ultra-processed food consumption and increasing unprocessed foods in the diet may be effective health promotion strategies.

In contrast to adult studies, the association between the degree of food processing and obesity measures among children have been inconsistent (9, 47). Prospective studies found that greater ultra-processed food intake was associated with greater waist circumference in young children (aged 4–8 years old) (19), and increased adiposity trajectories tracing into early adulthood (from ages 7 to 24 years) (20). In contrast, cross-sectional studies in school-aged children and adolescents found no associations between ultra-processed or unprocessed food consumption and BMI (48) or additional indicators of obesity, including waist circumference and waist-to-height ratio (49), whereas another cross-sectional study identified a significant association between the consumption of unprocessed or minimally processed foods and excess weight among adolescents, but not ultra-processed foods (50). Our study found that energy intake from ultra-processed foods was not significantly associated with measures of obesity including BMI, waist circumference, body weight, or percent body fat in children. However, processed foods were significantly associated with BMI z-scores in children, but this small positive association may not be biologically relevant. In particular, un-disaggregated culinary preparations, which represent an important part of energy consumed by children, may be influencing the association between the consumption of processed foods and BMI z-scores. Significant inverse associations between unprocessed or minimally processed food intake and waist circumference were also identified in children. One possible explanation for the absence of this relationship in children may be due to their young age, as preschool-aged children are also rapidly growing. As the effect of ultra-processed foods was small, it may be difficult to disentangle this from normal growth (51).

While the underlying mechanisms driving the associations between the degree of food processing and risk of obesity are yet to be fully elucidated, there are several plausible mechanisms. According to the protein leverage hypothesis, the overconsumption of ultra-processed foods is driven by the need to minimize variations in absolute protein intake as a result of the reduction in dietary protein density of these foods (52). Thus, the resulting energy overconsumption from increased intake of low-protein ultra-processed foods may drive weight gain. Another possible explanation for the influence of ultra-processed foods on obesity risk is the tendency of these foods to displace nutrient-dense, unprocessed or minimally processed foods in the diet and thus, promote poor dietary patterns (53, 54). The high palatability, convenience, affordability and lower satiety of these foods may also facilitate over-eating and weight gain (53–56). A recent study proposed that compared to unprocessed foods, ultra-processed foods have a greater "energy intake rate" (a measure of energy density combined with eating rate that quantifies the rate at which energy from foods is consumed), which may further promote excess energy intakes (57). However, the proposed mechanisms by which ultra-processed foods may be related to anthropometric measures warrant further study. Further, along with dietary intake, other factors which were not examined in the current study, including physical activity, sedentary behavior, smoking status, alcohol consumption status, lipid profiles, genetics, and psychological factors, also contribute to the development of obesity and related diseases (49, 58–61).

The present study found that ultra-processed foods contributed over 40% of total energy intake in the diet of both parents and children. The relatively high intake of ultra-processed foods found in this study is also supported by previous reports (62–64). Data on household food acquisition of ultra-processed foods from countries including Canada, Brazil, Mexico, Taiwan, and Sweden showed marked increases in the contribution of ultra-processed foods, and consequent decreases in the contribution of unprocessed foods in the diet (65–69). Nationally representative dietary surveys also confirmed that ultra-processed foods represent half of the total energy in the diet of high-income countries including the USA (56%) (70), Canada (48%) (25), and UK (57%) (45). The findings of our study corroborate this data, as ultra-processed foods comprised a greater proportion of energy intake in the diet of Canadian households of middle to high-income parents (44%) and their preschool-aged children (41%), relative to the other less processed food categories. The high intakes of ultra-processed foods among preschool-aged children in our study is concerning since dietary patterns during early years of life may shape food preferences in adulthood, which could translate into the development of chronic diseases associated with poor diet (27). Further, the overall dietary intake of children in our study closely resembled the energy intake values of parents, highlighting the importance of assessing dietary patterns within the family unit. In support of our findings, studies have shown that parental dietary patterns and the food environment influence children's feeding behaviors (28, 71). Thus, the family environment may facilitate the consumption of ultra-processed foods and should be taken into account when designing nutrition intervention strategies to elicit behavior changes (30).

This study contributes to our understanding of the associations between the degree of food processing and anthropometric indicators of obesity among a unique family based cohort of preschool-aged children. Our study explored cross-sectional associations in both parents and children, providing additional evidence for the importance of the family environment in shaping the early life dietary preferences of children. In addition, the use of individual-level dietary data in this study, as opposed to household surveys of food purchases, provides data that is more reflective of the current diet. Although this study employs a novel approach examining the association between the degree of food processing and obesity risk in a family based cohort, some limitations should be considered. Our sample included predominantly White participants from middle to high-income households and so, the generalizability of these findings to ethnically diverse and low-income households may be limited. Also, dietary reporting using the self-administered ASA24 may be subject to recall bias and underreporting of foods deemed less healthful by participants due to social desirability bias. However, these concerns are mitigated as the ASA24 is a validated dietary assessment tool for use in both adults and children. Further, culinary preparations were not disaggregated as participants were not required to report detailed recipes. Instead, culinary preparations were classified as unprocessed or minimally processed foods or processed foods, thereby potentially overestimating the dietary contribution of these categories and underestimating the contribution of processed culinary ingredients and ultra-processed foods. Due to the cross-sectional nature of our analyses, the potential causal mechanisms underlying the results of this study and the longitudinal effects of the associations between the degree of food processing and anthropometric measures in families require further study.

Conclusion

Our study found relatively high intakes of ultra-processed foods in the diets of Canadian parents and their preschool-aged children. Ultra-processed foods were found to be positively associated with anthropometric indicators of obesity in parents, but not children. Unprocessed foods were inversely associated with abdominal obesity in both parents and children, and body weight in parents only. The overall findings from this study support the current recommendation by health professionals to reduce the consumption of ultra-processed foods and promote the consumption of unprocessed or minimally processed foods as an effort to prevent obesity. Additionally, further studies exploring prospective associations between the degree of food processing and obesity markers in a diverse family based cohort are warranted.

Data availability statement

The datasets presented in this article are not readily available because due to Research Ethics Board restrictions and participant confidentiality, we do not make participant data publicly available. The GFHS welcomes external collaborators. Interested investigators can contact GFHS investigators to explore this option, which preserves participant confidentiality and meets the requirements of our Research Ethics Board, to protect human subjects. Requests to access the datasets should be directed to DM, davidma@uoguelph.ca.

Ethics statement

The studies involving human participants were reviewed and approved by University of Guelph Research Ethics Board approved the study (REB #17-07-003). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

RA and DM designed the research, and analyzed and interpreted the data. RA conducted the research, wrote the first draft of the manuscript, and had primary responsibility for final content. All authors contributed to the review and revision of the manuscript, read, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Raquel Mendonça,
Universidade Federal de Ouro Preto, Brazil

REVIEWED BY
Jordana Herzog Siqueira,
Federal University of Espirito Santo, Brazil
Renata Moreira,
Federal University of Tocantins, Brazil

*CORRESPONDENCE
Lívia Carolina Sobrinho Rudakoff
livia.rudakoff@ifma.edu.br

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Ultra-processed food consumption is associated with increase in fat mass and decrease in lean mass in Brazilian women: A cohort study

Lívia Carolina Sobrinho Rudakoff[1]*, Elma Izze da Silva Magalhães[1], Poliana Cristina de Almeida Fonseca Viola[2], Bianca Rodrigues de Oliveira[1], Carla Cristine Nascimento da Silva Coelho[1], Maylla Luanna Barbosa Martins Bragança[1], Soraia Pinheiro Machado Arruda[3], Viviane Cunha Cardoso[4], Heloisa Bettiol[4], Marco Antonio Barbieri[4], Renata Bertazzi Levy[5] and Antônio Augusto Moura da Silva[5]

[1]Post-Graduate Program in Collective Health, Public Health Department, Federal University of Maranhão, São Luís, Brazil, [2]Nutrition Department, Federal University of Piauí, Teresina, Brazil, [3]Post-Graduate Program in Collective Health, State University of Ceará, Fortaleza, Brazil, [4]Post-Graduate Program in Child and Adolescent Health, University of São Paulo, Ribeirão Preto, Brazil, [5]Department of Preventive Medicine, School of Medicine, University of São Paulo, São Paulo, Brazil

Objective: To investigate the association between ultra-processed food consumption at 23–25 years of age and measurements of body composition–fat mass, fat mass distribution and lean mass at 37–39 years of age in Brazilian adults.

Methods: 1978/1979 birth cohort study conducted with healthy adults from Ribeirão Preto, São Paulo, Brazil. A total of 1,021 individuals participated in the fat mass analysis (measured by air displacement plethysmography) and 815 in the lean mass analysis and fat mass distribution (assessed by dual energy X-ray absorptiometry). Food consumption was evaluated by a food frequency questionnaire. Food items were grouped according to the level of processing as per the NOVA classification. Ultra-processed food consumption was expressed as a percentage of total daily intake (g/day). Linear regression models were used to estimate the effect of ultra-processed food consumption (g/day) on body mass index, body fat percentage, fat mass index, android fat, gynoid fat, android-gynoid fat ratio, lean mass percentage, lean mass index and appendicular lean mass index. Marginal plots were produced to visualize interactions.

Results: The mean daily ultra-processed food consumption in grams was 35.8% (813.3 g). There was an association between ultra-processed food consumption and increase in body mass index, body fat percentage, fat mass index, android fat and gynoid fat and decrease in lean mass percentage, only in women.

Conclusion: A high ultra-processed food consumption is associated with a long-term increase in fat mass and a decrease in lean mass in adult women.

KEYWORDS

ultra-processed foods (UPFs), food consumption, diet, body composition, body fat

Introduction

The body composition assessment is important to describe and monitor nutritional status with accuracy, in addition to several physiological processes and pathological conditions, making it possible to identify individuals at risk and plan appropriate therapeutic interventions (1, 2). Excess fat mass (FM) is related to higher morbidity and mortality, and the metabolic risk related to fat accumulation is strongly dependent on its distribution (3). The monitoring of lean mass (LM) allows the identification of cachexia, sarcopenia and sarcopenic obesity, situations that are related to increased functional decline and high risk of disease and mortality (2).

Several factors affect body composition, and diet and level of physical activity are some of the most important aspects to be considered (4, 5). Low-carbohydrate diets, for example, may be effective in decreasing FM in obese individuals (6), whereas high-protein diets may have a beneficial effect on weight loss, increasing FM loss and preserving fat-free mass (FFM) (7). However, the diet effect on body composition varies according to age, nutritional quality of this diet, nutritional status, sex of individuals, level of physical activity, hormonal load, genetics, and lifestyle, among other factors (8–10).

The nutritional quality of diets has been widely evaluated using the NOVA food classification system, which groups food according to the nature, purpose and extent of industrial processing rather than in terms of nutrients and food types (11–13). Food items are grouped into 4 groups: Group 1 - Raw or minimally processed foods; Group 2 - Processed culinary ingredients; Group 3 - Processed foods, and Group 4 - Ultra-processed foods (UPF) (11–13), the last consisting of industrial formulations made from numerous food-derived ingredients, with little or no whole food, often added with additives that modify their sensory attributes. UPF has, on average, higher energy density, more free sugar, more total and saturated fats and lower concentrations of fiber, proteins, vitamins, and minerals (11–13). Thus, diets with high UPF participation have their nutritional quality impaired (14–18).

UPF is associated with increased overweight, abdominal obesity, hypertension, coronary and cerebrovascular diseases, dyslipidemia, metabolic syndrome, gastrointestinal disorders, diabetes mellitus, depression, asthma, frailty in the older people, total and breast cancer, and increased overall mortality (14–18). In Brazil, according to the 2017-2018 Household Budget Survey (POF 2017–2018), the mean UPF contribution to the total dietary energy intake (TDEI) of the diet was 19.7% (19).

Although an association between UPF consumption and excess weight was demonstrated (20–24), few studies estimated its long-term effect on body composition. Costa et al. (25) found that a 100 g increase in the UPF contribution to the daily intake of children at age six was associated with a gain of 0.14 kg/m^2 in the fat mass index (FMI) at age 11. In adolescents, a 1% increase in the UPF contribution percentage to total dietary energy intake was associated with a 0.04 kg decrease in muscle mass (MM) and a 0.01 kg/m^2 decrease in lean mass index (LMI) (26). A cohort study that evaluated associations between UPF consumption and adiposity trajectories from childhood to early adulthood (from seven to 24 years of age) showed an annual increase of 0.03 kg/m^2 in FMI in the fifth quintile of UPF consumption when compared to the first (27).

To date, to our knowledge, only one longitudinal study evaluated the association between high UPF consumption and changes in body composition (assessed by great validity methods) in adults and older people. Individuals aged 55–75 years with metabolic syndrome, overweight and obesity were followed for 12 months and it was found that a 10% daily increase in UPF consumption was associated with an accumulation of 0.09 g in visceral fat, 0.05 in android-gynoid fat ratio (AGR), and 0.09% in body fat percentage (BFP) (28). No studies were found that evaluated the UPF effect on the LM of adults.

In this sense, the aim of this study was to investigate, prospectively, the association between UPF consumption at 23–25 years of age and the composition and distribution of body fat and lean mass at 37–39 years in adults

Abbreviations: ADP, Air displacement plethysmography; AG, Android fat; AGR, Android-gynoid fat ratio; ALMI, Appendicular lean mass index; BPA, Bisphenol A; BFP, Body fat percentage; BMI, Body mass index; NCDs, Chronic noncommunicable diseases; DXA, Dual-energy R-ray absorptiometry; FM, Fat mass; FMI, Fat mass index; FFM, Fat-free mass; FFQ, Food frequency questionnaire; GF, Gynoid fat; LM, Lean mass; LMI, Lean mass index; LMP, Lean mass percentage; MM, Muscle mass; POF, Household Budget Survey; SSB, Sugar-sweetened beverages; TDEI, Total dietary energy intake; UPF, Ultra-processed food.

followed by the 1978/1979 Ribeirão Preto birth cohort study (São Paulo, Brazil).

Methods

Study design and study population

This is a prospective cohort study with data from a matrix research entitled "Estudo epidemiológico-social da saúde perinatal em Ribeirão Preto, SP" (29). Data from three of the five phases of the cohort study were used: baseline (birth) (1978/1979); the fourth phase, at 23–25 years of age (2002/2004), and the fifth phase, when the participants were between 37 and 39 years old (2016/2017). At birth (baseline), 6,827 children born in hospitals to mothers residing in Ribeirão Preto were evaluated. In the fourth phase, 2,063 individuals were evaluated, characterizing 30.2% of the original cohort. In the fifth phase, data were collected from 1,775 participants. Further details of each cohort stage, its objectives, methods, and eligible individuals were previously published (29, 30).

For this study, the assessment encompassed only those born in a single birth, who participated in the fourth and fifth phases of the cohort, whose food consumption data were collected at 23–25 years and body composition data were evaluated at 37–39 years, totaling 1,050 individuals for the analysis of fat mass (Body Mass Index–BMI, BFP, FMI) and 839 for the analysis of lean mass (percentage of muscle mass–LMP, LMI and appendicular lean mass index -ALMI) and distribution of body fat (android fat–AF, gynoid fat–GF and AGR). Individuals at the extremes of caloric intake (above or below three standard deviations of the mean total caloric intake, $n = 08$) and at the extremes of body composition (below the 1^{st} percentile and above the 99^{th} percentile) (21 for adiposity and 17 for lean mass and distribution of body fat) were excluded, totaling 1,021 individuals for analysis of adiposity and 815 for analysis of lean mass and distribution of body fat. In Supplementary Figure S1, a detailed flowchart of the cohort phases is shown.

Food consumption assessment (exposure variable)

Food consumption was assessed using a semi-quantitative Food Frequency Questionnaire (FFQ) adapted for use in programs for the prevention of Chronic Noncommunicable Diseases (NCDs) aimed at adults, including the age group assessed in this study (31). The questionnaire was applied by nutritionists, with the aid of a photo album to help estimate the portions consumed. The FFQ contained 75 food items, referring to food consumption in the last 12 months, with options for the number of times (0–9) and the frequency of consumption (daily, weekly, or monthly), and the reference average portion size, for the individual to estimate whether the portion usually consumed was small (smaller than that presented), medium (equal to that presented), or large (greater than that presented) (32). The food portions were classified according to the percentage distribution of weights equivalent to the household measures referred to in the 24-h dietary recall (24 hDR), previously applied as part of the FFQ elaboration. The average portion presented in each food item represented the 50th percentile and the small and large portions, respectively, the 25th and 75th percentiles. The methodology of the validation has been described in detail by Molina et al. (32).

To obtain the consumption of each food item in grams (g) or milliliters (ml), the referred frequencies were converted into daily frequency and multiplied by the serving size. The nutrient and energy intake of each food item was calculated using food composition tables (33–35). In the case of alcoholic beverages, kilocalories from alcohol were also considered. The sum of calories from all food items reported in the FFQ made up the total calories consumed. The consumption of macronutrients, fiber and alcohol was adjusted to 1,000 kcal/gram.

Food items were grouped according to NOVA classification into raw or minimally processed, processed, and ultra-processed foods. Culinary ingredients were grouped together with the group of raw/minimally processed foods, in a group called "food preparations" (36). When food items from different groups were grouped in the FFQ, it was decided to divide the share of these food items into more than one group, by means of an estimate, using as a parameter the consumption observed in the state of São Paulo according to the Brazilian Household Budget Survey (2002–2003) (37), the closest to the data collection period of our presentation. Finally, the percentage of participation of calories and grams from UPF consumed by participants in the daily total of grams and calories, respectively, was calculated.

Body composition assessment (outcome)

Body weight (kg) and height (cm) were evaluated in the fifth phase. Trained researchers performed these measurements using a high-precision scale coupled to an Air Displacement Plethysmography (ADP) device (COSMED BodPod® Gold Standard, Concord, USA) with 100 gram graduation. Height was measured using portable AlturaExata® stadiometers with 0.1 cm accuracy (Belo Horizonte, Brazil). Participants were assessed in an upright position, with the head oriented according to the Frankfort horizontal plane.

BMI was calculated by dividing weight in kilograms by height in square meters (kg/m^2). Body adiposity was measured by LMI and BFP. This was evaluated by the ADP and converted into kg of fat mass, considering the individual's weight. The FMI was obtained by dividing the fat mass (kg) by the height in square meters (38).

To assess LM and body fat distribution, dual-energy R-ray absorptiometry (DXA) was used. The GE Healthcare® Lunar Prodigy Densitometer (Chicago, United States) was used in a full-body scan with the participant immobile in the supine position on the table, with legs together and arms along the body. The body weight estimated by DXA was different from the weight obtained with the digital scale. Thus, it was necessary to adjust the MM by calculating the LMP estimated by DXA. The adjusted MM (kg) was then obtained by multiplying the LMP by the weight recorded on the digital scale (26). Appendicular lean mass (ALM) (kg) was calculated as the sum of the MM of the arms and legs. The MMI (kg/m^2) was calculated as the ratio between the adjusted LM (kg) and the height in square meters, while the ALMI (kg/m^2) was obtained as the ratio between the ALM (kg) and height in square meters (39).

Body fat distribution was assessed by measuring AF (kg) and GF (kg). The AF region comprised the space between the ribs and the pelvis, and the GF comprised the region relative to the hip and thighs. The lateral limits established were the lines of the arms when in a normal position for the full-body scan. Central fat distribution was measured through the ratio between AF and GF (AGR) (28).

Other variables of interest

At 23–25 years of age, data were obtained by trained personnel using structured questionnaires, and the following variables were evaluated: sex (male/female); age categorized in years (23 years/24 years/25 years); race/ethnic group (white/black/brown/yellow or indigenous); family income in minimum wages (<5 minimum wages/5–9.9 minimum wages/or ≥10 minimum wages); marital status (with a partner/without a partner); current smoking (yes/no); television (TV) and reading time (<3 h/ ≥3 h per day) (40), and anabolic steroid use (yes/no). The level of physical activity was assessed according to the International Physical Activity Questionnaire–IPAQ (high, moderate, and low) (41).

In order to avoid possible bias due to loss to follow-up (74.0%) that occurred during the cohort period, weighting was performed by the inverse of the selection probability (participation in the follow-up). For that, the following baseline variables were used: type of birth (cesarean section/vaginal); sex (male/female); birth weight (<2500 g / ≥2,500 g); parity (1 birth/ 2–4 births/ ≥5 births); prematurity (preterm birth <37 weeks/ term birth ≥37 weeks); maternal age (<20 years/20–34 years/> 34 years); maternal schooling (≤4 years of schooling/ 5–8 years of schooling/ 9–11 years of schooling/ ≥12 years of schooling); maternal smoking during pregnancy (yes/no); maternal marital status (with a partner/without a partner), number of prenatal consultations (0 consultations/1–5 consultations/ ≥6 consultations); maternal occupation (non-manual/skilled manual/unskilled manual); length at birth (< 50 cm/ ≥50 cm), and family income in quartiles.

Data analysis

This study had as an exposure variable the proportion of consumption in grams of UPF at 23–25 years of age, obtained by the percentage of total daily intake (daily intake of UPF (g)/total daily intake of foods and beverages(g)*100). Outcomes were body adiposity (measured by BMI, BFP and LMI), distribution of body fat (GA, GG and AGR) and lean mass (MMP, LMI and ALMI), assessed at 37–39 years. All variables were treated continuously.

In order to establish the minimum set of adjustment variables, reduce confounder bias, collision bias and avoid the inclusion of unnecessary variables in multivariate analysis, a theoretical model was developed based on the construction of a Directed Acyclic Graph (DAG), through the online DAGitty (version 3.0) software (42), according to Supplementary Figure S2. The variables to compose the minimum adjustment set for confounders identified in the DAG by the backdoor criterion (42) were: age, skin color, family income, sex, marital status, level of physical activity, smoking, screen time, anabolic steroid use, and alcohol consumption. As in the FFQ, alcohol consumption was already taken into account within the groups, and it was decided not to use it as an adjustment variable. In addition, as analyzes were performed by % of UPF grams, the TDEI variable was included in the adjustment. All adjustment variables were considered at 23–25 years of age.

The variables used to analyze loss to follow-up were evaluated using the Chi-square test and, by means of logistic regression, a weight was generated for each participant, obtained by the inverse of the selection probability.

Statistical analyzes were performed using Stata® (version 14.0) software (Stata Corporation, College Station, Texas, USA). Qualitative variables were described in absolute and relative frequencies and quantitative variables in means and standard deviations. To assess the normality of distribution of variables, asymmetry and kurtosis coefficients were used.

Sociodemographic and lifestyle variables were compared using Pearson's chi-square or Fisher's exact test. Means of total calorie consumption, food groups, macronutrients, fiber, alcohol, and body composition were compared between sexes using Student's t-test. The significance level was set at 0.05 and a 95% confidence interval was adopted.

Linear regression models were fitted to verify the association between UPF consumption and body composition measurements. Unadjusted and adjusted analyzes were performed for confounder variables identified in the DAG from the backdoor criterion. Analyzes were performed with

TABLE 1 Sociodemographic characteristics and lifestyle habits of adults aged 23–25 years participating in the 1978/1979 Ribeirão Preto birth cohort study (São Paulo, Brazil, 2002–2004).

Variable	Total		Male		Female		*p*-value**
	n	%*	*n*	%*	*n*	%*	
Sex	1,021	100.0	481	50.8	540	49.3	-
Age							
23	315	30.5	146	29.2	169	31.8	0.688
24	503	49.0	237	49.9	266	48.0	
25	203	20.5	98	20.9	105	20.2	
Race/Ethnic group							
White	665	61.7	311	61.8	354	61.6	0.507
Brown	293	31.3	136	30.1	157	32.5	
Black	52	5.9	27	6.7	25	5.1	
Yellow/Oriental	11	1.1	7	1.4	4	0.8	
Family income (in MW[a])							
<5	324	34.4	138	31.4	186	37.5	<0.001
5-9.9	329	30.9	147	29.7	182	32.0	
>9.9	395	26.7	168	32.3	127	21.0	
No information	73	8.0	28	6.6	45	9.5	
Marital status							
With a partner	314	31.4	121	26.1	193	36.9	<0.001
Without a partner	707	68.6	360	73.9	347	63.1	
Smoking							
No	857	82.9	392	80.6	465	85.2	0.074
Yes	164	17.1	89	19.4	75	14.8	
Physical activity level							
Low	498	49.2	276	57.9	222	40.3	<0.001
Moderate	311	29.9	137	27.5	174	32.3	
High	209	20.5	68	14.7	141	26.6	
No information	3	0.4	0	0.0	3	0.8	
Television and reading time							
<3 h	343	33.5	165	34.1	178	32.9	0.714
≥3 h	678	66.5	316	65.9	362	67.1	
Anabolic steroid use							
No	999	97.8	461	96.0	538	99.7	<0.001
Yes	22	2.2	20	4.0	2	0.3	

*Relative frequencies weighted by loss to follow-up.
**Pearson's chi-square or Fisher's exact test.
[a]MW: minimum wage, which from 2002 to 2004 ranged from R$ 200,00 to 260,00.

linear UPF consumption variables and, later, quadratic terms were added to investigate non-linear effects. The presence of possible interactions (UPF consumption and sex) was also tested. For interactions, a 0.10 significance level was considered. Based on the adjusted regression models, in the presence of interaction, conditional effects were plotted for each body composition outcome according to UPF consumption, for each sex (43). These conditional effects are statistics calculated from predictions of a previously fitted model on fixed values of some covariates and mean or otherwise integrating over the remaining covariates (44).

All analyzes were also performed to verify the association between the UPF consumption caloric percentage (in % kcal) and body composition, whose results are shown in Supplementary Tables S2–S4 and Supplementary Figures S3–S8. For these analyses, adjustment was performed for the variables selected in the DAG, with the exception of alcohol consumption. Furthermore, the TDEI variable was included in the adjustment.

TABLE 2 Food group consumption according to the NOVA classification and macronutrients and alcohol consumption by 23–25-year old participants (2002/2004) of the 1978/1979 Ribeirão Preto birth cohort study (São Paulo, Brazil).

Energy/Food group/ Macronutrients		All ($n = 1,021$) Mean	All SD	Male ($n = 481$) Mean	Male SD	Female ($n = 540$) Mean	Female SD	p-value*
Total dietary energy intake	Kcal	2,254.1	692.8	2,457.0	702.1	2,073.3	632.2	<0.001
Total consumption (in grams)	Grams/day	2,165.5	744.1	2,329.4	732.8	2,019.5	724.0	<0.001
Ultra-processed foods	Diet Kcal	877.1	426.2	912.6	441.4	845.5	409.9	0.011
	% TDEI	38.1	11.3	36.1	10.9	39.9	11.3	<0.001
	Grams/day	813.3	583.9	855.5	561.9	775.8	600.9	0.029
	% Grams/day	35.8	15.3	35.3	14.7	36.3	15.8	0.281
Processed foods	Diet Kcal	241.7	140.6	283.3	143.9	204.6	126.7	<0.001
	% TDEI	10.8	5.3	11.7	5.2	9.9	5.2	<0.001
	Grams/day	154.9	145.7	202.2	156.5	112.7	120.8	<0.001
	% Grams/day	7.2	5.7	8.9	6.1	5.6	4.8	<0.001
Food preparations[a]	Diet Kcal	1,132.5	385.1	1,258.7	396.6	1,020.2	337.3	<0.001
	% TDEI	51.1	11.3	52.1	11.4	50.1	11.2	0.006
	Grams/day	1,197.3	445.6	1,271.7	460.1	1,131.1	421.8	<0.001
	% Grams/day	57.0	15.2	55.9	14.6	58.1	15.7	0.020
Macronutrients and alcohol	Carbohydrates (g) /1000Kcal	139.8	16.4	136.8	16.0	142.6	16.2	<0.001
	Lipids (g) /1000Kcal	28.8	5.4	29.3	5.3	28.4	5.5	0.010
	Proteins (g) /1000Kcal	42.2	7.9	43.0	7.4	41.4	8.2	0.001
	Fibers (g) /1000Kcal	11.1	2.9	10.7	2.7	11.4	3.0	<0.001
	Alcohol (g) /1000kcal	1.8	2.6	2.5	2.8	1.2	2.2	<0.001
	Carbohydrates**	55.9	6.5	54.7	6.4	57.0	6.5	<0.001
	Proteins (%)**	16.9	3.2	17.2	3.0	16.6	3.3	0.001
	Lipids (%)**	25.9	4.9	26.4	4.8	25.6	4.9	0.011

TDEI, total dietary energy intake.
SD, Standard deviation.
*Student's t-test.
**The kilocalories from alcohol were included in the TDEI calculation, and then the final sum is not 100%.
[a]Group formed by Group 1 "Raw/minimally processed foods" plus Group 2 "Culinary ingredients".

Results

At 23–25 years of age, 50.8% were male, white (61.8%), without a partner (68.6%), non-smokers (82.9%), and with reading and TV time ≥3 h (66.5%). The most prevalent family income was <5 minimum wages (34.4%). Almost half (49.2%) of the participants had a low level of physical activity, followed by moderate (29.9%) and high (20.5%) levels. Only 2.2% used anabolic steroids (Table 1).

The average daily food consumption was 2,165.5g (±744.1 g), with 35.8% (±15.3%) coming from UPF, 7.2% (±5.7%) from processed foods, and 57.0 % (±15.2%) from food preparations. The mean UPF consumption (% grams) was 36.3% (±14.7%) among women and 35.3% (±15.8%) among men (Table 2).

There was a high consumption of sugar-sweetened beverages (SSB) (24.65% of the total food items/beverage consumed per day) by the sample studied. After these, the most consumed UPF was snacks, dairy products and candies. The most consumed food items/beverages in each group and the percentage contribution to the total dietary intake (in % of grams and in % of caloric contribution) are listed in Supplementary Tables S1, S2, respectively.

At 37–39 years of age, women had higher total body adiposity (BFP, FMI), distributed in the gynoid region, while men had higher BMI, and greater LM (LMP, LMI, ALMI) and AF (Table 3).

In the analysis in % grams, a longitudinal association was observed between UPF consumption and FMI (crude analysis: $\beta = 0.02$; 95%CI 0.00, 0.04; $p = 0.017$, and adjusted $\beta = 0.02$; 95%CI 0.00, 0.04; $p = 0.022$); and between UFP consumption and BFP (crude analysis: $\beta = 0.05$; 95%CI 0.00, 0.09; $p = 0.019$, and adjusted $\beta = 0.04$; 95%CI 0.00, 0.08; $p = 0.012$) (Table 4).

There was interaction between sex and UPF consumption for the BMI ($p = 0.058$), FMI ($p = 0.021$), BFP ($p = 0.010$), AF ($p = 0.005$), GF ($p = 0.017$) and LMP ($p = 0.002$) variables (Table 4). Therefore, the results of the linear regressions of the association between UPF consumption and these variables were

TABLE 3 Mean of body composition measurements at 37–39 years (2016/2017) according to sex of participants of the 1978/1979 Ribeirão Preto birth cohort study (São Paulo, Brazil).

Body composition measurements	**General mean ± SD**		***p*-value***
	Male ($n = 481$)	**Female ($n = 540$)**	
Body mass index (kg/m^2)	28.9 ± 4.4	28.1 ± 5.6	0.006
Body fat percentage (%)	26.4 ± 7.7	37.9 ± 8.3	<0.001
Fat mass index (kg/m^2)	7.9 ± 3.4	11.1 ± 4.3	<0.001
Android fat (kg)	2.6 ± 1.0	2.3 ± 1.1	<0.001
Gynoid fat (kg)	4.7 ± 1.6	6.0 ± 1.7	<0.001
Android/gynoid fat ratio	0.4 ± 0.2	0.02 ± 0.1	0.323
Lean fat percentage (%)	66.8 ± 6.5	54.9 ± 7.5	<0.001
Lean mass index (kg/m^2)	18.7 ± 1.7	14.7 ± 1.8	<0.001
Appendicular lean mass index (kg/m^2)	8.8 ± 0.9	6.4 ± 0.8	<0.001

*Student's t-test. SD, Standard deviation.

calculated conditional effects for each sex (Table 5). In the crude analysis, there was an association between UPF consumption and increased BMI (β = 0.04; 95%CI 0.01, 0.07; $p = 0.024$), FMI (β = 0.04; 95%CI 0.01,0.06; $p = 0.003$), BFP (β = 0.08; IC95% 0.03, 0.13; $p = 0.001$), AF (β = 0.01; IC95% 0.00, 0.01; $p = 0.007$), GF (β = 0.01; IC95% 0.00, 0.02; $p = 0.021$), and decrease in LMP (β = −0.06; 95%CI −0.11, −0.02; $p = 0.004$), only in women. In the adjusted analysis, a 10% increase in the percentage of UPF consumption (in grams) was associated with a longitudinal increase of 0.4 kg/m^2 in BMI (β = 0.04; 95%CI 0.01, 0.07; $p = 0.023$), 0, 4 kg/m^2 of LMI (β = 0.04; 95%CI 0.01,0.06; $p = 0.002$), 0.8% in BFP (β = 0.08; IC95% 0.04, 0.13; $p = <0.001$), 0.1 kg of AF ($\beta = 0.01$; 95%CI 0.00,0.01; $p = 0.003$), 0.1 kg of GF (β = 0.01; 95%CI 0.00, 0.02; $p = 0.011$), and a 0.7% decrease in LMP (β = −0.07; 95%CI −0.11, −0.03; $p = 0.001$), only in women (Table 5 and Supplementary Figures S3–S8).

In analyzes in % of caloric contribution, the longitudinal association was observed only in the crude analyzes for the FMI ($p = 0.001$), BFP ($p < 0.001$), GF ($p = 0.031$), AGR ($p = 0.021$), LMP ($p = 0.003$), LMI ($p = 0.003$) and ALMI ($p = 0.001$) variables. After adjustments, significance was maintained only for the BFP variable ($p = 0.042$) (Supplementary Table S3). There was interaction between sex and UPF consumption for the BMI ($p = 0.038$), FMI ($p = 0.018$), BFP ($p = 0.017$), AF ($p = 0.071$), GF ($p = 0.038$) and LMP ($p = 0.004$) variables (Supplementary Table S3). In the analysis of these conditional effects by sex, the crude analysis showed an association between UPF consumption and increased BMI (β = 0.05; 95%CI 0.00, 0.09; $p = 0.032$), FMI (β = 0.04; 95%CI 0.01, 0.08).; $p = 0.008$), BFP (β = 0.09; 95%CI 0.02, 0.16; $p = 0.007$), and decrease in LMP (β = −0.07; 95%CI −0.13, −0.004; $p = 0.038$), only in women. In the adjusted analysis, the 10% increase in the UPF consumption percentage was associated with a longitudinal increase of 0.5 kg/m^2 in BMI (β = 0.05; 95%CI 0.01, 0.09; $p = 0.016$), 0.5 kg/m^2 in FMI (β = 0.05; 95%CI 0.02, 0.08; $p = 0.003$), 1.1% in BFP (β = 0.11; 95%CI 0.04, 0.17; $p = 0.002$), and 0.8% decrease in LMP (β = −0.08; 95%CI −0.14, −0.02; $p = 0.006$), only in women (Supplementary Tables S3, S4 and Supplementary Figures S3–S8).

Quadratic terms of UPF consumption (in %grams and in % caloric contribution) were tested for all body composition variables, but there was no statistical significance.

Discussion

This study investigated the association between the UPF contribution percentage and the diet and body composition assessed by high validity methods in adults of a cohort study. The greatest UPF contribution to the diet was associated with an increase in fat and a decrease in lean mass years later, only among women. These findings demonstrate that a higher UPF consumption has a negative impact on the body composition of women in the long term, contributing to increasing the prevalence of overweight, which is also a risk factor for the emergence of other NCDs.

As limitations, we point out the use of the FFQ, a method that is subject to memory and measurement bias due to not counting the consumption of food items that are not listed, tending to overestimate food intake. In addition, the FFQ used was not originally constructed aimed at identifying food consumption according to the degree of processing, given that data collection took place in a period before the emergence of the NOVA classification, and some different food groups were placed in the same question. To minimize this limitation, adjustments were made, considering the estimates of food consumption for the state of São Paulo at the time of data collection (37). We reiterate, however, that the instrument used was adapted for use in NCD prevention programs aimed at adults, and was validated (32), reflecting the food consumption of the time, and although there are some limitations, the FFQ is a widely used method in epidemiological studies due to its low cost, practicality, ability to assess the usual diet without changing the pattern of food consumption (45), as long as the methodological aspects for its elaboration are carefully planned, ensuring data reliability and accuracy (45).

Another limitation was the use of the screen time variable, considering that the database only had information about TV time and reading in aggregate form. We emphasize that at the time of data collection (2002/2004), the use of screens such as computers, smartphones and video games, among others, was not yet so widespread in Brazil, therefore not appearing in the large population surveys carried out in the country until then (40). Finally, another limitation of this study involved the losses to follow-up. Inverse probability weighting was used to minimize the effects of these losses on analysis.

TABLE 4 Crude and adjusted linear regression analysis between ultra-processed foods consumption (% grams) at 23–25 years (2002/2004) and body composition measurements at 37–39 years (2016/2017) in participants of the 1978/1979 Ribeirão Preto birth cohort study (São Paulo, Brazil).

Body composition measurements	% Of ultra-processed foods grams			
	Crude analysis		Adjusted analysis[d]	
	β (95%CI)	*p*-value	β (95%CI)	*p*-value
Body mass index (kg/m²)				
a	0.02 (0.00, 0.04)	0.143	0.02 (0.00, 0.04)	0.135
b			−1.15 (−1.84, −0.45)	0.001
c	0.04 (0.00, 0.08)	0.064	0.04 (0.00, 0.08)	0.058
Fat mass index (kg/m2)				
a	0.02 (0.00, 0.04)	0.017	0.02 (0.00, 0.04)	0.022
b			2.79 (2.27, 3.32)	<0.001
c	0.04 (0.00, 0.07)	0.029	0.04 (0.00, 0.07)	0.021
Body fat percentage (%)				
a	0.05 (0.00, 0.09)	0.019	0.04 (0.00, 0.08)	0.012
b			10.54 (9.47, 11.63)	<0.001
c	0.09 (0.02, 0.15)	0.016	0.09 (0.02, 0.16)	0.010
Android fat (kg)				
a	0.002 (−0.002, 0.007)	0.338	0.003 (−0.001, 0.008)	0.512
b			−0.32 (−0.48, −0.17)	0.004
c	0.01 (0.00, 0.02)	0.007	0.01 (0.00, 0.02)	0.005
Gynoid fat (kg)				
a	0.006 (−0.003, 0.01)	0.165	0.006 (−0.002, 0.01)	0.147
b			1.18 (0.93, 1.43)	<0.001
c	0.02(0.00, 0.04)	0.015	0.02 (0.00, 0.04)	0.017
Android/gynoid fat ratio				
a	0.0002 (−0.0004, 0.0008)	0.597	0.0001 (−0.0004, 0.0006)	0.617
b			−0.17 (−0.19, −0.15)	<0.001
c	0.0005 (−0.0005, 0.001)	0.348	0.0006 (−0.0004, 0.002)	0.225
Lean mass percentage (%)				
a	−0.03 (−0.07, 0.02)	0.197	−0.02 (−0.06, 0.00)	0.173
b			−10.59 (−11.60, −9.58)	<0.001
c	−0.10 (−0.16, −0.03)	0.003	−0.10 (−0.16, −0.03)	0.002
Lean mass index (kg/m²)				
a	−0.005 (−0.02, 0.007)	0.447	−0.004 (−0.01, 0.00)	0.373
b			−3.75 (−4.00, −3.49)	<0.001
c	0.004 (−0.01, 0.02)	0.650	0.00 (−0.01, 0.02)	0.695
Appendicular lean mass index (kg/m²)				
a	−0.004 (−0.01, 0.00)	0.273	−0.003 (−0.007, 0.001)	0.168
b			−2.20 (−2.32, −2.07)	<0.001
c	0.00 (−0.007, 0.008)	0.916	0.00 (−0.008, 0.008)	0.925

[a]β coefficient of linear regression.
[b]β coefficient of linear regression for women.
[c]β coefficient of the interaction term between consumption of ultra-processed foods and sex.
[d]Analysis adjusted for sex, age, family income, marital status, television and reading time, physical activity level, smoking, anabolic steroid use, and total dietary energy intake.

As strengths, we highlight the fact that longitudinal studies that evaluated the body composition of adults with high validity methods are still scarce and, to date, there are no studies that have demonstrated associations between UPF consumption and the body composition of adults, especially the influence of UPF consumption on body lean mass.

The UPF contribution percentage in grams in the diet of adults in Ribeirão Preto was 35.8% (equivalent to 38.1% of

TABLE 5 Conditional effects of ultra-processed foods consumption (% grams) according to sex at 23–25 years (2002/2004) and body composition measurements at 37–39 years (2016/2017) in participants of the 1978/1979 Ribeirão Preto birth cohort study (São Paulo, Brazil).

Linear regression prediction of body composition measurements	% Of ultra-processed foods grams			
	Crude analysis		Adjusted analysis[a]	
	β (95%CI)	*p*-value	β (95%CI)	*p*-value
Body mass index (kg/m²)				
Men	0.00 (−0.03, 0.03)	0.758	0.00 (−0.04,0.03)	0.725
Women	0.04 (0.01, 0.07)	0.024	0.04 (0.01, 0.07)	0.023
Fat mass index (kg/m²)				
Men	0.00 (−0.02, 0.02)	0.967	0.00 (−0.03;0.02)	0.920
Women	0.04 (0.01, 0.06)	0.003	0.04 (0.01, 0.06)	0.002
Body fat percentage				
Men	0.00 (−0.06, 0.05)	0.862	0.00 (−0.05, 0.05)	0.870
Women	0.08 (0.03, 0.13)	0.001	0.08 (0.04, 0.13)	<0.001
Android fat (kg)				
Men	0.00 (−0.01, 0.00)	0.193	0.00 (−0.01, 0.00)	0.226
Women	0.01 (0.00, 0.01)	0.007	0.01 (0.00, 0.01)	0.003
Gynoid fat (kg)				
Men	−0.01 (−0.02, 0.00)	0.269	−0.01 (−0.02, 0.00)	0.366
Women	0.01 (0.00, 0.02)	0.021	0.01 (0.00, 0.02)	0.011
Lean mass percentage (%)				
Men	0.04 (−0.01, 0.08)	0.144	0.03 (−0.02, 0.08)	0.173
Women	−0.06 (−0.11, −0.02)	0.004	−0.07 (−0.11, −0.03)	0.001

[a] Analysis adjusted for sex, age, family income, marital status, television and reading time, physical activity level, smoking, anabolic steroid use and total dietary energy intake.

TDEI). This represents practically double the Brazilian average (19.7% of TDEI), according to the 2017–2018 Household Budget Survey (POF) (19), which can be explained by the fact that the municipality is at more advanced levels of nutritional transition compared to other regions of the country, characterized by high caloric intake, high consumption of foods with low nutritional quality, and a sedentary lifestyle. Furthermore, young individuals, in the age group of the population of this study, tend to consume high levels of UPF in Brazil (46). A high UPF consumption in the diet of adults has been evidenced by several studies, indicating a high risk of developing NCDs due to the unbalanced nutritional composition of these products (14–22).

A highlight is the high ultra-processed SSB (soft drinks and industrialized juices) consumption, corresponding, in grams, to practically ¼ of the total of food items/beverages consumed/day (24.7%), which is equivalent to 10.24% in caloric contribution percentage (Supplementary Tables S1, S2). High SSB consumption is associated with potential hormonal dysregulation, insulin resistance, dyslipidemia, increased adiposity and obesity, and is also related to obesogenic behaviors, such as sedentary lifestyle and high screen time (47, 48), lifestyle habits that have been common in the population of this study. In addition, a higher SSB consumption (but not the general UPF group) was associated with higher urinary concentrations of bisphenol A (BPA), an endocrine disruptor that is associated with increased prevalence of risk factors for abdominal obesity, diabetes and hypertension (48, 49).

The pattern of body composition found in this research, where women had higher levels of total adiposity and GF, and men had higher means of BMI, AF, AGR and lean mass was also found in other ethnic groups (38). This pattern can be explained due to biological differences (50, 51), represents a higher risk of sarcopenic obesity for women (51) and a higher risk of cardiovascular diseases and metabolic syndrome (52) for men considering that body fat distribution has a greater impact on cardio-metabolic risk than excess total adiposity (51).

Despite this pattern of body distribution, our results showed a deleterious effect of UPF only on the body composition of women, corroborating other evidence that associates UPF with excess body weight and consequent higher adiposity (20–22, 53–57), especially in women. In another Brazilian study, the authors found a positive association between UPF consumption and overweight and obesity in women, but not in men (21). In Switzerland, UPF was associated with excess body weight only in women (54). In South Korea, UPF was also associated with obesity only among women (55). In the United States, Juul et al. (20) observed significant positive associations between UPF consumption and overweight or obesity in both sexes, but with a more pronounced association among women, a result also found in the United Kingdom (20, 22).

Scientific evidence suggests that UPF promotes changes in body composition through a range of mechanisms, such as the unbalanced nutritional composition of foods and beverages, which favors increased energy and nutrient consumption and ingredients of low nutritional quality, such as refined sugars (11–18); the presence of food additives and contaminants produced during processing, which alter the profile and composition of the intestinal microbiota (56), and changes in the food matrix induced by food processing that seem to influence the kinetics of nutrient absorption and alterations in gut-brain satiety signaling (48, 53), among other mechanisms not yet clarified that interrelate, promoting inflammation, oxidative stress and consequent weight gain (48). The effects of these mechanisms appear to affect the sexes differently, with more impact on women. UPF is associated with a higher glycemic response, and women appear to be more sensitive to the UPF hyperglycemic effect than men (48). Besides, changes in the intestinal microbiota caused by UPF seem to affect men and women differently (56).

As for the distribution of body fat, a higher UPF consumption favored the increase in AF and GF, but not in AGR, also only among women. Despite the non-association with AGR, which is an indicator of abdominal obesity, UPF is found to be more harmful to women with regard to the association with an increase in AF, which is associated with a greater risk of cardiovascular outcomes and metabolic syndrome (28, 52). We emphasize that this association for AF may not have been found in the analysis in the UPF caloric contribution percentage due to the fact that the analysis in grams takes into account foods and beverages widely consumed by the population, which have a high content of additives and low caloric contribution, such as SSB, especially diet and light soft drinks.

An association between UPF consumption and a decrease in LMP was demonstrated only in women. Although no association was found for LMI and ALMI, which are indices relativized by height are commonly associated with the diagnosis of sarcopenia, especially the latter, these results are worrying given the importance of LM in maintaining the population's health and quality of life. LM provides useful information about an individual's health and nutrition, playing an important role in maintaining bone density, preserving strength, reducing the risk of injuries and falls, and improving metabolism and general health. Reduction in LM with age or due to sarcopenia is associated with decreased function and quality of life and the frailty development (57, 58). Thus, although the reduction in LM was not detected by the indices generally used in the diagnosis of sarcopenia, the decrease in LMP already points to a deleterious effect of UPF on LM, not having been detected by LMI and ALMI because this population is still found at the peak of the LM. Furthermore, this pattern of body distribution characterized by high adiposity and decreased LM in women points to the development of sarcopenic obesity, which makes them more prone to the development of diabetes mellitus, abdominal obesity, and an increased risk of death (59).

Conclusion

Our results indicate that the high UPF contribution percentage to the diet of Brazilian adults is associated with a longitudinal increase in FM and a decrease in LM only among women, favoring a deleterious composition pattern for females.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by Research Ethics Committee (CEP) of the University Hospital of FMRP-USP School of Medicine. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LR performed material preparation and data analysis and wrote the first draft of the manuscript. All authors commented on the other versions, contributed to the study conception and design, read, and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1006018/full#supplementary-material

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EDITED BY
Roberta Masella,
National Institute of Health (ISS), Italy

REVIEWED BY
Claudia Cataldo,
National Institute of Health (ISS), Italy
Annalisa Silenzi,
Independent Researcher, Rome, Italy

*CORRESPONDENCE
Mariana Carvalho de Menezes
mariana.menezes@ufop.edu.br

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Multiple health risk behaviors, including high consumption of ultra-processed foods and their implications for mental health during the COVID-19 pandemic

Hillary Nascimento Coletro[1], Raquel de Deus Mendonça[2], Adriana Lúcia Meireles[2], George Luiz Lins Machado-Coelho[3] and Mariana Carvalho de Menezes[2]*

[1]School of Nutrition, Research and Study Group on Nutrition and Public Health (GPENSC), Universidade Federal de Ouro Preto, Ouro Preto, Brazil, [2]Department of Clinical and Social Nutrition, School of Nutrition, Research and Study Group on Nutrition and Public Health (GPENSC), Universidade Federal de Ouro Preto, Ouro Preto, Brazil, [3]Laboratory of Epidemiology, School of Medicine, Universidade Federal de Ouro Preto, Ouro Preto, Brazil

Background and aim: The growing increase in diet- and behavior-related illnesses has drawn the attention of many epidemiologists who attribute such changes to the epidemiological and nutritional transition. Thus, this study aims to evaluate the association between the combined occurrence of health risk behaviors, such as sedentary lifestyles, high weekly consumption of ultra-processed foods (UPFs), and non-daily consumption of fruits and vegetables, and symptoms of anxiety or depression in adults.

Methods: This is a cross-sectional study based on an epidemiological survey in two Brazilian cities. The outcome, anxiety, and depression symptoms were assessed using the Generalized Anxiety Disorder 7-item (GAD-7) and the Patient Health Questionnaire-9 (PHQ-9). Food consumption was assessed using a qualitative food frequency questionnaire (FFQ) with reference to consumption in the last 3 months and categorized into the consumption of fruits and vegetables and the consumption of UPFs according to the NOVA classification. Sedentary behavior was assessed by considering the amount of sitting or reclining time per day reported by participants and categorized as less than 9 h of sitting or reclining and 9 h or more. For the analysis, adjusted Poisson regression (PR) was used to estimate the prevalence ratio and the 95% confidence interval (CI).

Results: Those with the health risk behaviors, non-daily consumption of fruits and vegetables, and high consumption of UPFs had a 2.6 higher prevalence ratio for symptoms of mental disorder (PR: 2.6 and 95%CI: 1.1–6.5), as well as those with all three health risk behaviors, had a 2.8 higher prevalence ratio for symptoms of mental disorder (PR: 2.8 and 95%CI: 1.3–6.1).

Conclusion: This study revealed that the existence of a combination of two and three health risk behaviors led to a higher prevalence of symptoms of anxiety or depression.

KEYWORDS

anxiety, depression, risk behaviors, fruit and vegetable consumption, ultra-processed food, sedentary behavior

Introduction

According to the International Classification of Diseases (ICD-11), mental disorders are diseases with unusual psychological manifestations that generate functional impairment, and may be the result of biological, social, genetic, physical, or chemical alterations (1). Individuals with mental disorders have a decreased life expectancy of 10–15 years compared to the general population (2). Between 1990 and 2019, the global number of disability-adjusted life-years (DALYs) due to mental disorders increased from 80.8 to 125.3 million, with depression and anxiety being the most prevalent disorders (3).

Depression is defined as a mental disorder in which a sad or irritable mood is present as a common symptom accompanied by cognitive and neurological changes such as difficulty concentrating, sleep disorders, anorexia, and memory changes, (4) while anxiety can be defined as an emotional reaction to aversive situations and can cause somatic manifestations and symptoms such as headache, tachycardia, and tremors, and psychic manifestations such as insecurity, insomnia, and irritability (5). In both cases, studies have shown that hyperactivity of the hypothalamic-pituitary-adrenal axis leads to excessive production of pro-inflammatory cytokines and a decrease in serotonin (6), which are related to lifestyle and health behaviors.

Mental disorders include not only intrinsic determinants such as the ability to cope with thoughts and emotions, but also social, lifestyle, economic, and environmental factors (7). In this scenario, the COVID-19 pandemic was declared in 2020, and negative psychological and behavioral experiences that could elicit extreme psychological stress and contribute to mental health problems were exacerbated. Examples include fear of infection, insecurity about the future, high mortality from SARS-CoV-2 (8), and several health measures enacted to contain high transmission of the disease (9). These measures altered the lifestyle of the entire population, especially work arrangements, social relationships, food consumption, and the practice of physical activity and exercise (10). Thus, the risk factors for the occurrence of disease and mental disorders were exacerbated and the cases of new illness increased. It is estimated that 53.2 million new cases of depression and 76.2 million new cases of anxiety worldwide are diagnosed after the beginning of the COVID-19 pandemic (11). In this regard, it is extremely important to understand how the coexistence of health risk behaviors affects mental health. Health risk behaviors typically have a synergistic effect, and the combination of two or more behaviors generally increases the risk of chronic disease when compared to the presence of each behavior individually (12, 13). Thus, it becomes vital to understand the effects of these combined behaviors on mental health as well.

Some important changes observed in the lifestyle of the population after the beginning of the COVID-19 pandemic refer to food consumption (14) and an increase in sedentary behavior (15). This happened because restrictive measures reduced the frequency of purchases of fresh foods such as fruits and vegetables (16) to the institution of work at home, and interrupted leisure-time physical activity outside the home (17). Also, a significant increase in the consumption of foods not prepared at home and ultra-processed foods (UPFs) due to their price (18), convenience (19), palatability (20), storage (21), and easy access in this health crisis (22). High consumption of UPFs, that is, produced by large-scale industrial processes, and excessive addition of salt, sugar, fat, and substances dedicated to industry (21), can cause vitamin, mineral, and protein deficiency, which can lead to high intake of saturated fat, sugar, salt, ingredients with strong flavor, and chemical additives (23) and is associated with many negative health outcomes including symptoms of anxiety and depression (24). Another expected risk behavior is the increased time in reclining and sitting positions, i.e., sedentary behavior (25). This behavior is associated with a variety of adverse physical health outcomes (26) and may be associated with mental disorders too (17), as people with more time in sedentary behavior experience more symptoms of anxiety and depression (27–29).

Thus, this work aims to evaluate the association between the co-occurrence of health risk behaviors (sedentary behavior, high weekly consumption of UPFs, and non-daily consumption of fruits and vegetables) and the occurrence of anxiety or depression symptoms in adults during the COVID-19 pandemic.

Materials and methods

Study design and location

This is a cross-sectional study based on a household epidemiological survey conducted in three stages during a critical moment of the COVID-19 pandemic, October and December of 2020, in two Brazilian cities. This study is part of the "Epidemiological surveillance of COVID-19 in the Inconfidentes Region/MG," as previously described by Meireles et al. (30).

This study took place in the cities of Ouro Preto and Mariana, Brazil, where a total of 108,170 people live in the urban areas of the two cities with a Municipal Human Development Index (MHDI) of 0.741 and 0.742, respectively (31).

Study population and sampling

Residents in the urban areas of both cities, more than 18 years old, were considered eligible for this study. The sample size was calculated with the population estimate by the 2010 demographic census (31) for the urban areas, 95% confidence level, design effect equal to 1.5, SARS-CoV-2 infection estimate of 3–10%, and precision, plus a 20% re-composition percentage for any losses, using the OpenEpi tool.

A stratified and cluster sampling design was adopted in three stages: census sector (probability proportional to the number of households), household (systematic sampling), and resident (random), to ensure the representativeness of different socioeconomic strata in the sample. Based on this calculation, 1,789 households were selected and agreed to participate in the study. Of these, 27 individuals were excluded because they did not finish the interview or because they did not collect the blood sample, an inclusion criterion of the survey "Epidemiological surveillance of COVID-19 in the Inconfidentes Region/MG." Another 46 individuals were excluded with incomplete answers on the scale assessing anxiety symptoms, and another 25 individuals were excluded with incomplete answers on the scale assessing depression symptoms. Therefore, 1,693 individuals were evaluated in this study.

Data collection

Data collection was conducted on weekends to increase the participation of residents. The process started by approaching households, randomly selecting an adult resident, and drawing lots for the face-to-face interviews.

Interviews were conducted by a trained team, and their health was tracked through periodic evaluation, including testing for anti-SARS-CoV-2. A face-to-face interview lasted around 40 min, using electronic devices.

The questionnaire contained registration data, sociodemographic and economic variables, lifestyle variables, and food consumption assessments.

Outcome variable: Symptoms of anxiety and depression

The presence of symptoms of anxiety and depression was assessed using two validated scales: the Generalized Anxiety Disorder 7-item (GAD-7) (32) assessed the symptoms of anxiety and Patient Health Questionnaire-9 (PHQ-9) (33) assessed the symptoms of depression.

Both scales included questions that assessed the frequency of situations that triggered the symptoms of anxiety and depression in the last 2 weeks. Each response [(i) none; (ii) several days; (iii) more than half of the days; and (iv) almost every day] has a punctuation that ranges from 0 to 3 points. The points for each answer were added, and the result of this sum was categorized as described by Kroenke et al. (33) and Lowe et al. (32). Thus, scores below 10 points on both scales were considered as minimal or mild symptoms of anxiety and depression, while a score $\geq$ 10 points was considered as moderate or severe symptoms for both diseases. From this categorization, the binary outcome variable was created, which considers the presence of symptoms of anxiety or depression when the individual achieves a score $\geq$10 points (32, 33).

Exposure variables: Food consumption and sedentary behavior

Food consumption was assessed using a qualitative food frequency questionnaire (FFQ), based on the national survey "Surveillance System for Risk and Protective Factors for Chronic Diseases by Telephone Survey (34)," referring to consumption in the last 3 months. The frequency of food consumption was reported on weekdays: [(i) never; (ii) 1–2 days/week; (iii) 3–4 days/week; (iv) 5–6 days/week; and (v) every day, including Saturday and Sunday].

For this study, foods were separated into fruit and vegetable and UPF groups. The consumption of fruits, vegetables, legumes, and dark green vegetables were grouped and categorized into daily consumption and non-daily consumption, and the latter was considered the investigated risk behavior.

For the second health risk behavior "high weekly consumption of UPFs," the foods that make up this group were chosen from the NOVA classification, an internationally recognized instrument that classifies foods based on the extent and purpose of processing and their implications on human health (35). NOVA classifies foods into four groups: (i) fresh or minimally processed foods; (ii) culinary ingredients; (iii) processed foods; and (iv) UPFs (21). For this study, we only used the last group as a proxy for unhealthy eating, UPFs that stands for foods with the highest extent and purpose of processing were formulated with several techniques and many ingredients, including non-natural substances (21). To create this exposure variable, we consider the sum of the weekly consumption frequencies of all UPFs in the FFQ: soft drinks, chocolate drinks and artificial yogurt, cookies, packaged snacks, instant noodles, frozen products, processed meats, sweetbreads, and sweets (Figure 1), considering that these are the most consumed UPFs in the country (36, 37). Then, we categorized this variable into

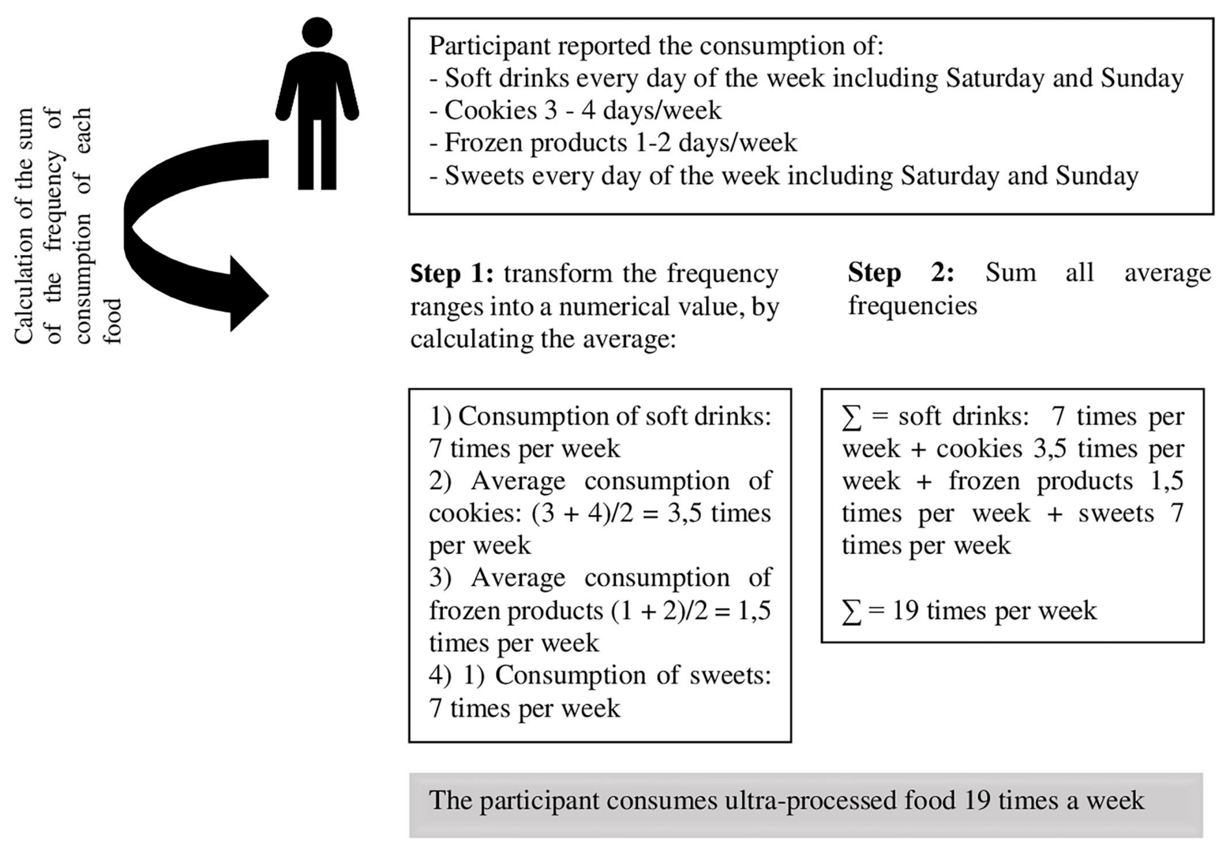

FIGURE 1
An example of how the exposure variable, high consumption of ultra-processed foods, was created, COVID Inconfidentes 2020.

consumption below the average weekly frequency (<15.15 times/week) and consumption equal to or above the average weekly frequency (≥15.15 times/week), and the last one was considered the risk behavior under investigation.

Sedentary behavior was assessed by considering the amount of time sitting or reclining per day (38) reported by participants. Based on data from a recent meta-regression analysis of more than 1 million participants that suggest a cut-off point for sedentary behavior, this variable was categorized into less than 9 h of sitting or reclining time and 9 h or more of sitting or reclining time per day, and the last one was considered the risk behavior under investigation (39, 40).

Covariates

Sociodemographic variables were investigated to describe the sample and explore possible confounding. Sociodemographic variables investigated were sex, age (grouping: 18–34, 35–59, and 60 years old or more), marital status (with or without a partner), skin color (white, black/brown, indigenous, yellow and others, in which the participant could mention another color not previously mentioned), education (never attended school, 1–9 years of study, or more than 9 years of study), family income (up to two minimum wages MW, two to four MW, or more than four MW), employed or not at the time of the interview, and change in income after the COVID-19 pandemic (reduced, increased, or no change).

Statistical analysis

Initially, we calculated the sample weight of each selected unit (census sector, household, and individual) separately for each city to increase the representativeness of the sample.

For descriptive analysis, the proportion and 95% confidence intervals (CIs) were used. To evaluate the relationship between the descriptive variables and the outcome, Pearson's Chi-squared test was used with a 5% significance level.

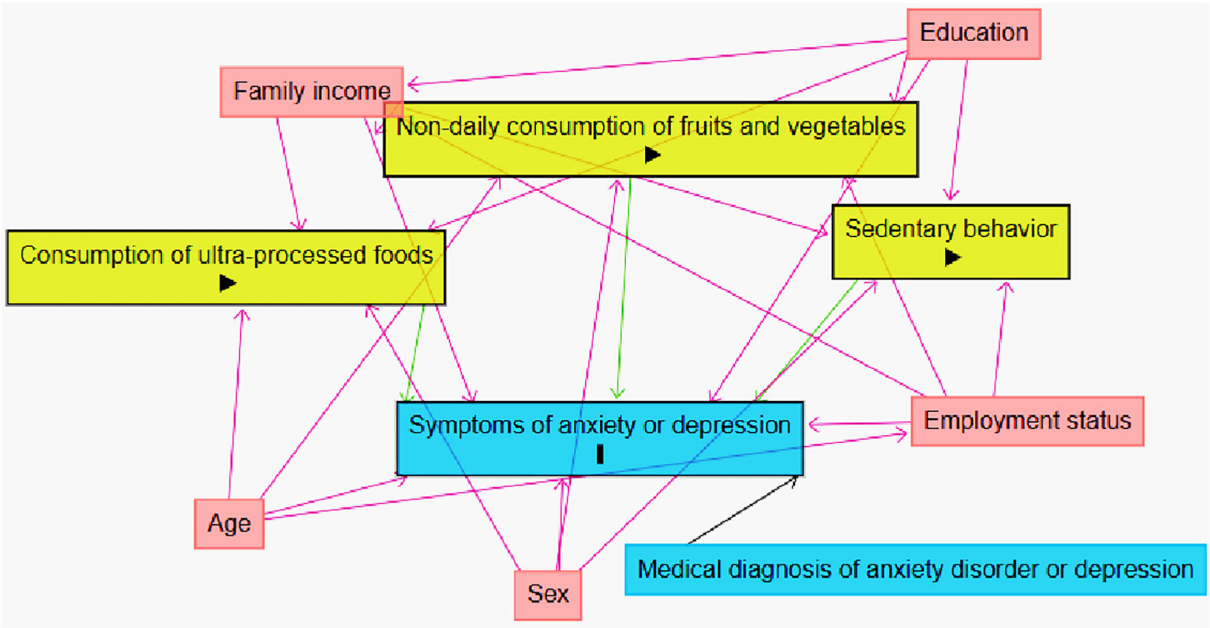

FIGURE 2
Directed Acyclic Graph (DAG) for the association between anxiety or depression symptoms and health risk behavior, with possible confounding variables, COVID Inconfidentes 2020. Causal connections are represented by arrows; [blue box] represents the outcome; [yellow box] represents the exposure variables; [pink box] represents the adjustment variables.

To confirm the hypothesis of an association between health risk behaviors and symptoms of anxiety or depression, a variable was created, which was made up of the sum of the health risk behaviors ranging from 0 to 3, where 0 indicated no health risk behaviors, 1 indicated the presence of one of the assessed health risk behaviors (non-daily fruits and vegetables, having high consumption of UPF, and having a sedentary behavior), 2 indicated the presence of two of the assessed health risk behaviors, and 3 indicated the presence of all of the assessed health risk behaviors. A multivariate analysis was performed using Poisson regression (PR) with the prevalence ratio and respective 95%CI for binary outcomes.

In addition, eight patterns of health risk behaviors were created: (i) having none of the studied health risk behaviors (a pattern that can be used as a reference for analysis); (ii) having only non-daily fruit and vegetable consumption as a health risk behavior; (iii) having only high UPF consumption as a health risk behavior; (iv) having only sedentary behavior as a health risk behavior; (v) non-daily fruits and vegetables and having high UPF consumption; (vi) non-daily fruits and vegetables and having sedentary behavior; (vii) having high consumption of UPF and sedentary behavior; and (viii) non-daily fruits and vegetables, having high consumption of UPF, and having sedentary behavior, and additive interaction analysis was used to verify whether there are differences in prevalence ratios from the combination of different health risk behaviors for symptoms of anxiety or depression. An additive interaction is defined as a differential reduction in the absolute risk associated with one factor between different levels of other factors, and aims to assess the attributable risk estimate based on absolute differences between prevalence ratios (41, 42).

To select appropriate adjustment variables, we created a Directed Acyclic Graph (DAG) (Figure 2), considering exposures (non-daily fruit and vegetable consumption, high weekly consumption of UPF, and sedentary behavior), the outcome (anxiety or depression symptoms), and possible confounding variables. To avoid unnecessary adjustments, a minimal and sufficient set of adjustment variables was defined: sex, age, family income, employment status, and education.

The analysis was performed using Stata software version 15.1 (Stata Corporation, College Station, Texas), using the command "svy," which considers a complex sample design.

Ethics approval

The study was approved by the Research Ethics Committee of the Universidade Federal de Minas Gerais (Protocol

No. 4.135.077), and all participants signed the written informed consent.

Results

Of the participants, 1,693 were eligible for this study, and 27.6% reported symptoms of anxiety or depression (Figure 3).

The majority of the samples were women (51.1%), aged 35 to 59 years (45.8%), married (53.4%), brown or black in skin color (69.5%), had studied more than 9 years (77.4%), and had a family income less than twice the minimum wage (40.5%). In addition, most of them reported that they had a job during the interview period (52.9%) and that their income had not changed since the beginning of the COVID-19 pandemic (54.9%) (Table 1). Among those with symptoms of anxiety or depression, 18.5% reported sedentary behavior, 91.4% did not consume fruits and vegetables daily, and 55.3% consumed larger amounts of UPFs, as indicated by the abovementioned average weekly frequency.

When evaluating the combined occurrence of health risk behaviors, we observe that among individuals affected by symptoms of depression or anxiety, 4.8% had not received an assessment of health risk behavior, 33.1% had one health risk behavior, 51.9% had two health risk behaviors, and 10.0% had all three health risk behaviors at the same time (Figure 3).

In a multivariate regression analysis that combined the three health risk behaviors (sedentary behavior, non-daily consumption of fruits and vegetables, and high consumption of UPFs) with the presence of symptoms of anxiety or depression (Figure 4), it was possible to identify that those who combined diet-related risk behaviors (non-daily consumption of fruits and vegetables and high consumption of UPFs) had a 2.6 higher PR for symptoms of mental disorder (PR: 2.6 and 95% CI: 1.1–6.5), and those who engaged in the three risk behaviors simultaneously had a PR 2.8 higher for symptoms of mental disorder (PR: 2.8 and 95% CI: 1.3–6.1).

Furthermore, in a multivariate regression analysis of the association between the co-occurrence of health risk behaviors and the presence of symptoms of anxiety or depression (Figure 5), those with two and three health risk behaviors were observed to have a 2.5 and 2.8 higher PR for symptoms of mentaldisorder during the COVID-19 pandemic (PR: 2.5 and 95% CI: 1.1–6.0/ PR: 2.8 and 95%CI: 1.3–6.1).

Discussion

This study revealed a high prevalence of mental disorder symptoms, given the high prevalence of symptoms of anxiety and depression in Brazilian adults during the COVID-19 pandemic. This prevalence may be explained by the fear of the disease and its implications for health, uncertainties about the spread of the virus and its treatment, the high mortality rates, and the loss of family members and relatives, in addition to the disruption of daily routines and lifestyles marked by the imposition of restrictive measures characterized by social distance (8), the restriction of physical and in-person trade (43), the decrease in physical activity during leisure time and the increase in sedentary behavior (44, 45), increased alcohol consumption (46, 47), a decreased purchase of fresh foods, and increased impulse buying (48), especially of ready-to-eat foods with high durability (49, 50), characterizing health risk behaviors. Studies have shown that engaging in these behaviors, especially those related to comfort, may be a way for people to manage psychological distress and stressful situations (51, 52).

The isolated prevalence of health risk behaviors, especially those associated with mortality and the development of chronic non-communicable diseases, has been a widely explored theme; however, there are few studies that seek to investigate the combination of health risk behaviors and their association with mental health in a pandemic context, to identify the different lifestyle patterns and the possible synergistic effects of these behaviors (12, 13). Usually, health risk behaviors have a synergistic effect, changing the influence of one behavior on another. Furthermore, it is understood that lifestyle-related behaviors share contextual determinants, acting directly on the development of negative habits that lead to illness (52). Thus, the data presented here, have important implications for public health, as they help to identify which health risk behaviors grouped together, aiding in the development of an integrative approach for effective interventions and targeted initiatives for the prevention of mental health conditions.

Our data reveal that the combined risk behaviors, non-daily consumption of fruits and vegetables, and high consumption of UPFs had a higher prevalence ratio for symptoms of mental disorder. Epidemiological evidences suggest a relationship between food consumption and poor mental health through inflammatory reactions and deficiency of nutrients and neurotransmitters (53, 54). Excessive consumption of carbohydrates and sugar has been described as a risk factor for mental disorders due to an increase in neuroinflammation (55). Moreover, in addition to the macronutrient composition of UPFs, their non-natural ingredients, such as additives, colorings, flavorings, and sweeteners, induce changes in the human microbiota that can cause intestinal dysbiosis and mediate inflammatory processes that start in the gut and extend to the brain and can disrupt the production of important neurotransmitters responsible for feelings of wellbeing and happiness (56, 57).

In contrast, the consumption of fibers, present in larger quantities in fruits and vegetables, is associated with good overall health, as they are metabolized into short-chain fatty acids, which are important anti-inflammatory agents (58). In addition, these fresh foods are good sources of complex vitamins B, D, and E, and play an import role in modulating brain functions related to cognitive performance, preventing neurodegenerative

TABLE 1 Sociodemographic and mental health characteristics according to the outcome, the presence of symptoms of anxiety and depression, COVID Inconfidentes 2020.

Variables	Total % (95%CI)	Absence of symptoms of mental disorder	Presence of symptoms of mental disorder	P- value*
Sex[a]				0.001
Male	48.90 (41.67–56.18)	54.00 (46.45–61.36)	35.59 (24.62–48.30)	
Female	51.10 (43.82–58.33)	46.00 (38.64–53.55)	64.41 (51.70–75.38)	
Age[a]				0.144
18 to 34 years	36.52 (31.92–41.38)	33.88 (27.39–41.05)	43.41 (31.94–55.64)	
35 to 59 years	45.87 (41.34–50.47)	46.08 (39.39–52.91)	45.33 (35.47–55.58)	
≥ 60 years	17.61 (14.46–21.28)	20.04 (16.00–24.80)	11.26 (7.79–15.99)	
Marital status[a]				0.071
Married	53.41 (47.38–59.34)	55.86 (50.27–61.30)	47.01 (36.27–58.03)	
Not married	46.59 (40.66–52.62)	44.14 (38.70–49.73)	52.99 (41.97–63.73)	
Skin color[a]				0.275
White	26.10 (20.98–31.97)	23.93 (18.38–30.54)	31.73 (22.28–42.99)	
Brown and black	69.53 (63.23 - 75.17)	71.63 (65.44–77.11)	64.05 (52.57–74.12)	
Indigenous, yellow and others	4.37 (2.88–6.59)	4.43 (2.48–7.82)	4.21 (2.27–7.69)	
Education[a]				0.369
Never attended school	1.53 (0.06–3.54)	1,16 (0.03–0.37)	0.25 (0.07 —0.79)	
1 to 9 years	21.05 (17.15–25.57)	22.29 (17.69–27.68)	17.81 (12.56–24.63)	
> 9 years	77.41 (72.69–81.53)	76.54 (71.03–81.29)	79.69 (72.17–85.58)	
Family income[a]				0.497
≤ 2 MW[b]	40.59 (35.20–46.21)	42.08 (34.70–49.84)	36.70 (26.98–47.64)	
> 2 to ≤ 4 MW[b]	31.99 (26.81–37.67)	32.35 (26.98–38.24)	32.26 (20.39–46.98)	
> 4 MW[b]	27.42 (22.41–33.08)	25.56 (19.81–32.32)	31.03 (23.26–40.06)	
Working status[a]				0.549
Be employed	52.95 (48.09–57.75)	54.18 (47.09–61.10)	49.74 (39.50–60.00)	
Be unemployed	47.05 (42.25–51.91)	45.82 (38.90–52.91)	50.26 (40.00–60.50)	
Change in income after the COVID-19 pandemic[a]				0.100
Yes, it has reduced	37.29 (31.81–43.12)	36.71 (31.11–42.70)	38.80 (29.51–48.98)	
Yes, it has increased	7.79 (4.59–12.91)	5.31 (3.17–8.75)	14.26 (5.22–33.43)	
No change	54.92 (50.57–59.20)	57.98 (51.33–64.35)	46.94 (36.28–57.88)	
Health risk factors				
Sedentary behavior[a]				0.292
Yes	15.44 (12.30–19.21)	14.22 (11.03–18.15)	18.56 (11.76–28.05)	
No	81.44 (71.95–88.24)	85.78 (81.85–88.97)	81.44 (71.95–88.24)	
Non-daily fruit and vegetable consumption[a]				0.008
Yes	83.87 (78.56–88.07)	80.95 (72.79–87.10)	91.49 (87.86–94.11)	
No	16.13 (11.93–21.44)	19.05 (12.90–27.21)	8.51 (5.89–12.14)	
High weekly consumption of ultra-processed foods[a]				0.009
Yes	42.62 (38.49–46.86)	37.73 (32.42–43.36)	55.31 (44.55–65.60)	
No	57.38 (53.14–61.51)	62.27 (56.64–67.58)	44.69 (34.40–55.45)	

[a] Values expressed as proportion and 95% confidence interval (CI); [b] MW: Minimum wage of the year when data collection occurred, 2020—BRL 1,045.00 or about USD 194; *Statistically significant *p*-values; Not married, Widowed, divorced, and single.

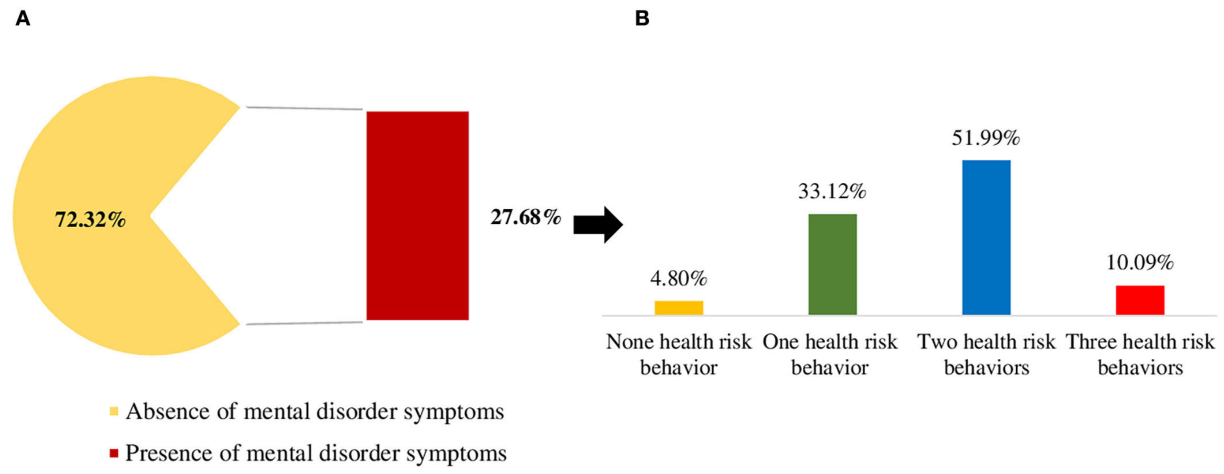

FIGURE 3
Prevalence of health risk behaviors among individuals with symptoms of anxiety or depression, COVID Inconfidentes 2020. **(A)** Prevalence of mental disorder symptoms. **(B)** Prevalence of the combined occurrence of health risk behaviors among those with mental disorder symptoms. The health risk behaviors: sedentary behavior (≥9 h/day), non-daily consumption of fruits and vegetables, and high weekly consumption of ultra-processed foods (≥15.15 times per week).

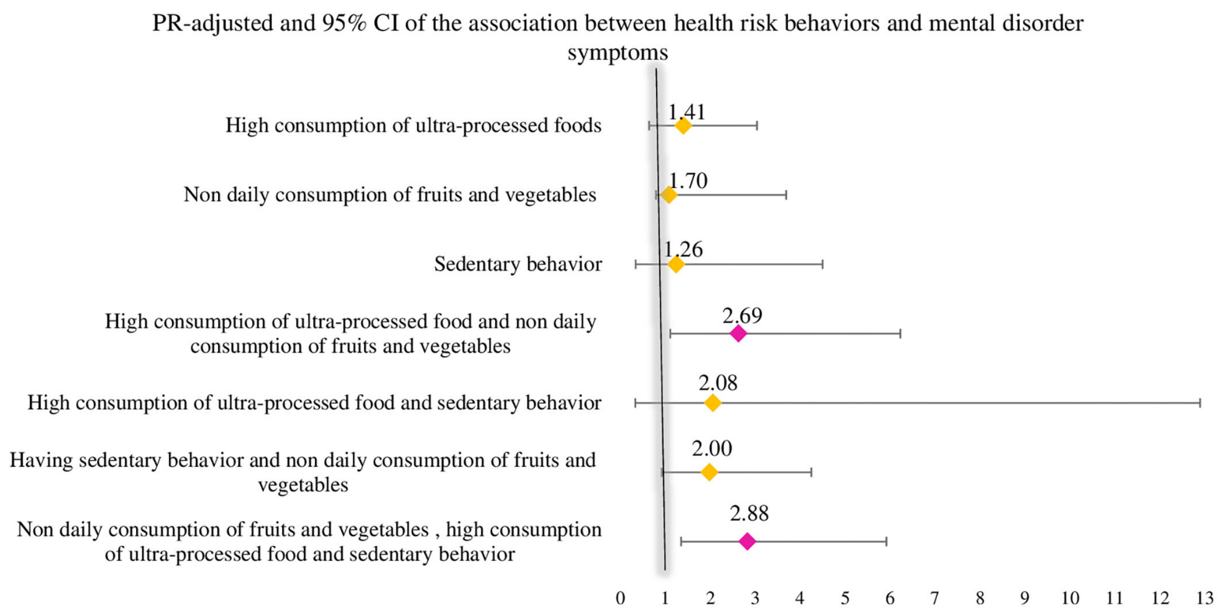

FIGURE 4
Prevalence ratio and 95% confidence interval (CI) for the interaction analysis between the co-occurrence of health risk behaviors and the presence of symptoms of mental disorder, COVID Inconfidentes 2020. Combined analysis to verify the existence of an association between the outcome (presence of depression or anxiety symptom) and the explanatory variables, given as health risk behaviors sedentary behavior, non-daily consumption of fruits and vegetables, and high weekly consumption of ultra-processed foods. The analysis was adjusted for sex, age, family income, having a job, and education.

disorders, and protection against oxidative stress (59). A survey of our group that evaluates food consumption according to the degree of processing and symptoms of anxiety and depression showed an inverse association between a higher consumption of fresh/minimally processed foods and the prevalence of depression symptoms, as well as a direct association between a higher consumption of UPFs and a higher prevalence ratio of depression symptoms (24, 60, 61).

When evaluating diet-related health risk behaviors combined with sedentary behavior, a higher prevalence ratio

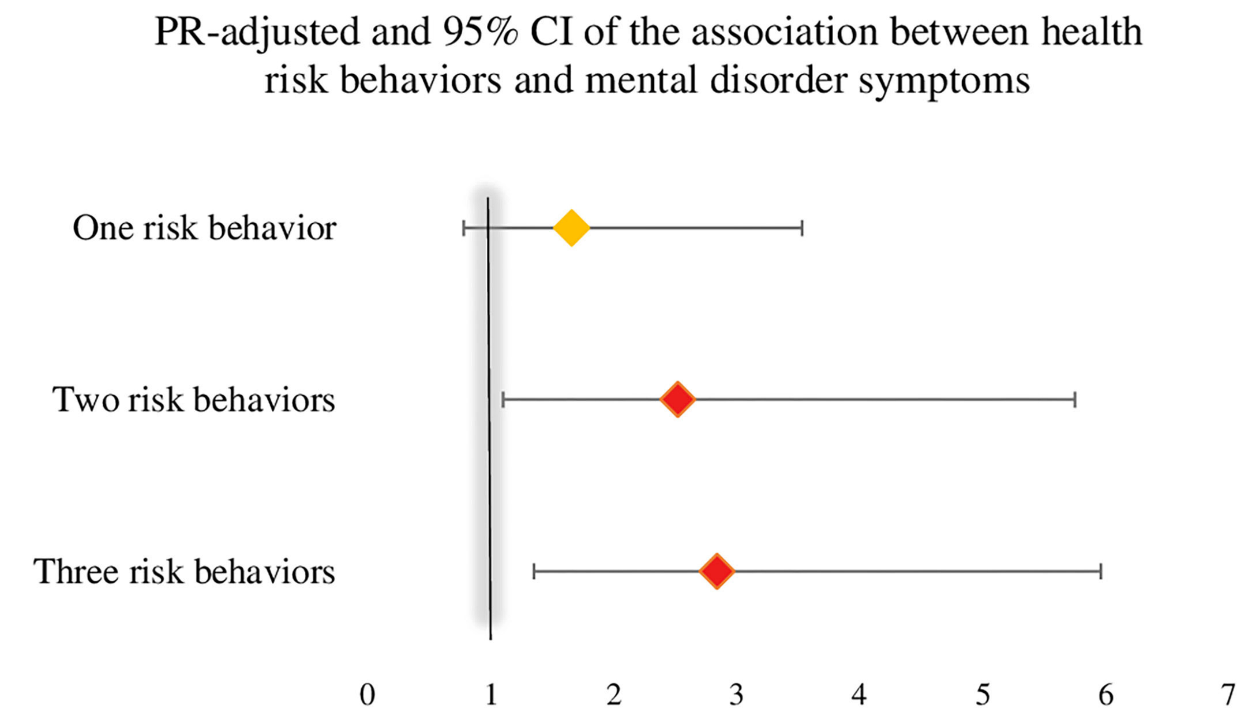

FIGURE 5
Prevalence ratio and 95% CI for the association between the co-occurrence health risk behaviors and the presence of symptoms of mental disorder, COVID Inconfidentes 2020. Poisson regression analysis to verify the existence of an association between the outcome (presence of depression or anxiety symptom) and the explanatory variables, given as health risk behaviors sedentary behavior, non-daily consumption of fruits and vegetables, and high weekly consumption of ultra-processed foods. The analysis was adjusted for sex, age, family income, having a job, and education.

was observed for mental disorder symptoms. Sedentary behavior has been studied as a risk factor for mental illness as screen-based sedentary behaviors, such as the use of computer, television (TV), and social media, are likely to induce addiction and poor sleep quality, which can maximize levels of mental distress (15, 62). Furthermore, it is suggested that the greater the time spent in sedentary behavior, the less social interaction and, therefore, the greater the feeling of loneliness and sadness (63, 64). Another biological mechanism explaining the association between sedentary behavior and mental disorders is that increased screen exposure in sitting or reclining time can reduce serum brain-derived neurotrophic factor, which in normal amounts is associated with cardiovascular health, cognitive development, and good mental health (65). A meta-analysis showed that after the beginning of the COVID-19 pandemic, children increased their time spent sitting or reclining by approximately 159.5 min/day, while adults increased their time spent in sedentary behavior by 126.9 min/day, which was negatively correlated with overall mental health, depression, anxiety, and quality of life (66).

In this regard, this paper adds data that demonstrate scientific evidence on the health consequences, in addition to SARS-CoV-2 infection, derived from the COVID-19 pandemic, highlighting the urgent need for public policies capable of jointly controlling health risk behaviors, such as the regulation of the production and sale of UPFs, to promote policies to improve food quality and health. The ingredients in ultra-processed products make them sugary or salty, often high in saturated fats or trans fats, and poor in micronutrients and other bioactive compounds, which are associated with many negative health outcomes (23). Thus, fiscal policies (67–69) warning labels (70, 71), marketing restrictions (72, 73), and incentives to consume fresh/minimally processed foods (21) are fundamental and should be the next steps to control UPF consumption, as guided by the World Health Organization (WHO), which recommends the consumption of five servings of fruits and vegetables per day (74).

Sedentary behaviors can be influenced by environmental attributes in specific contexts. Evidence suggests that it is important to increase the number of breaks in sedentary time, stand up and move after 30 min of uninterrupted sitting, for example, when watching TV or using a computer, and to replace leisure time sitting or reclining by time spent in physical activity (38, 75). As well as it is necessary to regulate public policies that can mitigate sedentary behaviors, either by reformulating urban settings encouraging more physical exercise practices, such as bike paths, walking trails, and parks, and reformulating the policies that refer to workers' health because most sedentary behaviors occur during the workday (76, 77).

Despite the significant findings, this study has some limitations. First, it is a cross-sectional study, which does not allow causal inferences to be established. The explanatory variables of food consumption were measured from a qualitative point of view, with information on the weekly frequency of their consumption, without the possibility of numerically quantifying the consumption. However, the use of a qualitative FFQ with the most consumed foods by the study population is a very important method to report the quality of the diet in general. Sedentary behavior was categorized based on a cut-off point proposed by a meta-analysis as it does not have an official measure. In addition, the outcome was assessed according to the presence of symptoms of anxiety or depression, measured by scales, and not by medical diagnosis, and the possibility of misclassification, if the participant did not answer correctly. However, the scales used have been validated (78, 79). Meanwhile, it is important to highlight that a robust methodology was used during a difficult time of the pandemic, considering that face-to-face interviews allow greater accuracy of the information obtained, while the probabilistic sample selection and sample weight provided statistical power to the study.

In conclusion, this study revealed that the existence of a combination of two and three health risk behaviors led to a higher prevalence of symptoms of anxiety or depression, considering that diet-related risk behaviors as a whole stood out as an important risk for mental disorder symptoms. We suggest the use of multi-behavioral interventions as a promising strategy for managing multifactorial morbidities (such as mental disorders), especially when considering the complexity of behaviors associated with individual lifestyle (80, 81). In addition, it should be considered as the institution and regulation of public policies aimed at structuring an urban setting to allow the population to exercise and live a healthy lifestyle, with full access to establishments for the production and sale of natural foods and places for physical activity and exercise. Furthermore, we reinforce the importance of the construction of guidelines based on the Food Guide for the Brazilian Population (21) and the Physical Activity Guide for the Brazilian population (82), to control high consumption of UPFs, encourage the consumption of natural foods, reduce sedentary behavior, and encourage physical activity, especially in the post-pandemic period.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors upon request, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Research Ethics Committee of the Universidade Federal de Minas Gerais (Protocol No. 4.135.077). The patients/participants provided their written informed consent to participate in this study.

Author contributions

HC: data collection supervision, conception and study design, analysis and interpretation of data, writing the manuscript, critical review, and final approval. RM: analysis and interpretation of data, critical review, and final approval. AM and GM-C: conception and coordination of data collection, critical review, management of financial resources, and final approval. MM: conception and study design, analysis and interpretation of data, critical review, supervision, and final approval. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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EDITED BY
Raquel Mendonça,
Universidade Federal de Ouro Preto,
Brazil

REVIEWED BY
Zoe Colombet,
University of Liverpool,
United Kingdom
Adriana Meireles,
Universidade Federal de Ouro Preto,
Brazil

*CORRESPONDENCE
Eduardo Augusto Fernandes Nilson
eduardo.nilson@fiocruz.br

†These authors have contributed
equally to this work

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The estimated burden of ultra-processed foods on cardiovascular disease outcomes in Brazil: A modeling study

Eduardo Augusto Fernandes Nilson[1,2*†], Gerson Ferrari[3,4†], Maria Laura da Costa Louzada[5†], Renata Bertazzi Levy[6†], Carlos Augusto Monteiro[1†] and Leandro F. M. Rezende[7†]

[1]Center for Epidemiological Research in Nutrition and Public Health, University of São Paulo, São Paulo, Brazil, [2]Oswaldo Cruz Foundation-Fiocruz, Brasília, Brazil, [3]Escuela de Ciencias de la Actividad Física, el Deporte y la Salud, Universidad de Santiago de Chile (USACH), Santiago, Chile, [4]Facultad de Ciencias de la Salud, Universidad Autónoma de Chile, Santiago, Chile, [5]Departamento de Nutrição, Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brazil, [6]Department of Preventive Medicine, Faculdade de Medicina FMUSP, Universidade de São Paulo, São Paulo, Brazil, [7]Department of Preventive Medicine, Escola Paulista de Medicina, Universidade Federal de São Paulo, São Paulo, Brazil

Introduction: Ultra-processed foods (UPF) have been associated with an increased risk of cardiovascular diseases (CVD). This study aimed to estimate CVD premature deaths, incident cases, and disability adjusted life-years (DALYs) attributable to the consumption of UPF in Brazilian adults in 2019.

Methods: A validated a comparative risk assessment model was adapted to estimate the burden of major CVD outcomes (coronary heart disease and stroke) attributable to the consumption of UPF in Brazilian adults aged 30 to 69 years. The model inputs included nationally representative data of the UPF contribution to the total energy of the diet, national official demographic records, CVD outcomes (incidence, deaths and DALYs) from the Global Burden of Disease study for 2019, and relative risks from meta-analysis studies.

Results: We estimated that approximately 19,200 premature deaths (95% uncertainty intervals – UI, 7,097 to 32,353), 74,900 new cases (95% UI, 25,983 to 128,725), and 883,000 DALYs/year (95% UI, 324,279 to 1,492,593) from CVD were attributable to the consumption of UPF in Brazil, corresponding to about 22% of the premature deaths from CVD and to 33% of the total premature all-cause deaths attributable to UPF intake among Brazilian adults. Reducing UPF consumption by 10% in the adult population would avert approximately 11% of the premature CVD deaths, equivalent to 2,100 deaths/year (95% UI, 697 to 4,511). A 20% reduction in UPF intake would avert approximately 21% of the premature CVD deaths or 4,100 deaths (95% UI, 1,413 to 8,047), and a 50% reduction in UPF intake would avert about 52% of the premature CVD deaths, corresponding to 9,900 deaths/year (95% UI, 3,682 to 17,820). If UPF consumption among adults was reduced to that of the first quintile of UPF intake in the baseline scenario, approximately 81% of the premature CVD deaths would be averted, corresponding to some 15,600 deaths/year (95% UI, 5,229 to 27,519).

Conclusion: Our study estimated a high burden of premature CVD outcomes attributable to the consumption of UPF in Brazil. Our findings support food policies aimed at reducing the consumption of UPF, such as fiscal and regulatory policies, which are imperative to prevent CVD in Brazil.

KEYWORDS

ultra-processed foods, CVD, mortality, incidence, DALYs, modeling

Introduction

As defined by the Nova food classification system, which considers the purpose and extent of industrial food processing, ultra-processed foods (UPF) are industrially manufactured formulations typically ready for consumption made of ingredients derived from foods (oils, fats, sugars, starch, protein isolates) and food additives with cosmetic function, containing little or no whole natural food (1). The ingredients and industrial techniques in their fabrication aim to create low-cost production, profitable, and extremely palatable and convenient products, which have gradually replaced unprocessed or minimally processed foods and culinary preparations in different countries (2).

Recent meta-analyses have consistently found significant dose-response associations between the dietary share of UPF and increased risk of all-cause deaths and non-communicable diseases, including cardiovascular diseases (CVD) (3–6). UPF are associated with an overall deterioration of nutritional quality of the diets (7) and a plethora of other postulated mechanisms associated with the presence of non-sugar sweeteners, emulsifiers and other additives (8), contaminants newly formed during processing or released from synthetic packaging (9, 10), and significant changes to the food matrix, leading to a highly degraded physical structure of food products (11). As a consequence, UPF are associated with low satiety potential, high glycemic loads (12), and inflammatory diseases, such as inflammatory bowel diseases and metabolic syndrome, possibly through modified gut microbiota and host–microbiota interactions (13). Specifically, regarding CVD risks, the mechanisms of action of UPF are not limited to the so-called critical nutrients, such as sodium, sugars and unhealthy fats, and include dysglycemia, insulin resistance, hypertension, and increased risk of obesity (14).

The Nova food classification has been increasingly used in dietary surveys and studies, including cohorts and meta-analyses in different countries, and, in Brazil, it was incorporated in the national dietary surveys (15, 16) and it provides the rationale for the National Dietary Guidelines (17, 18).

Over half of the total dietary energy consumed in certain high-income countries come from UPF, while sales of UPF have risen particularly in middle-income countries (19). In Brazil, the contribution of UPF to total energy intake increased by one third from 2002/2003 to 2017/2018, reaching 19.4% of the total energy (20, 21).

Despite the existing modeling studies to estimate the potential impact of specific dietary risk factors, especially of macro and micronutrient intakes and specific food groups (22), the health effects of dietary patterns based on the purpose and extent of food processing on morbimortality are scarce (23–25). Our previous study estimated that, approximately, 10.5% (57 thousand) of the all-cause premature deaths in 2019 were attributable to the consumption of UPF. Reducing the contribution of UPF to the total energy intake by 10 to 50% would, respectively, avert some 5.9 thousand to 29.3 thousand deaths (10.3% to 51.4% of the attributable deaths) in the year of reference (25). Alternatively, if UPF intake reached levels of consumption such as those from Mexico (29.8%) or the United States (57.0%), the attributable deaths would double or quadruple, respectively (26–28).

In this study, we aimed to estimate premature deaths, incidence, and disability adjusted life-years (DALYs) from CVD attributable to the consumption of UPF in Brazilian adults in 2019. We also estimated the potential impact of alternative scenarios of consumption of UPFs on CVD prevention.

Materials and methods

Study design

This study adapted a previously validated comparative risk assessment model (25) to estimate the burden of CVD deaths, new cases, and DALYs attributable to the consumption of UPF and to estimate the potential impact of reducing the consumption of UPF by 10, 20, and 50% and to the 1st quintile of UPF intake of the baseline scenario on these indicators.

The datasets used in the models are described in detail in **Table 1**, and the modeling details are presented in the **Supplementary material**. The modeling process involves (i) estimating the baseline intakes of UPF using dietary survey data representative of the Brazilian population, (ii) estimating the changes in UPF intake for each age- and sex-group for each counterfactual scenario; and finally (iii) estimating the effect of changes in UPF intake on the major CVD outcomes (ischaemic heart disease and stroke) through comparative risk assessment analysis.

Consumption of ultra-processed foods

The consumption of foods and beverages in Brazilian were obtained through a 2 non-consecutive 24-hour food recall from the Brazilian Dietary Survey 2017–2018 for adults by sex and age-groups (30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, and 65–69 years) (16). Foods and beverages were classified based on the NOVA classification into 4 major groups: unprocessed or minimally processed foods, processed culinary ingredients, processed foods, and UPF (1). The contribution of UPF to total energy intake was computed as the ratio of the mean energy from UPF food group over the mean total energy intake (**Supplementary Table 1**).

Comparative risk assessment analysis

Within each sex-and-age-stratum, we calculated the estimated relative risks (RR) for UPF intake and coronary heart disease (CHD) and stroke considering intervals of 0.1% of participation of UPF in the diets from 0.0 (RR = 1.00 for CHD and stroke) to 22.0% (RR = 1.29 for CHD and RR = 1.34 for stroke), according to a meta-analysis by Pagliai et al. (4), and extrapolated the RR for contributions up to 100%. The meta-analysis was chosen because it provides robust risk factor-disease evidence through the comparison of well-defined "high risk" vs "low risk" groups. This meta-analysis was based on a random-effects model for pooled analysis of the association of ultra-processed food consumption with increased risk of deaths from ischaemic heart disease and stroke from three prospective cohort studies (31–33), including 2,501 cases.

The distribution of UPF consumption in each age- and sex-stratum considered a log-linear function for the mean participation of UPF in the energy of the diet and its standard deviation and the corresponding national population.

Finally, within each sex-and-age-stratum and for each scenario, we estimated the potential impact fraction (PIF) for the outcomes (o) in each age group (a) and sex (s) through the following formula:

$$PIF_{oas} = \frac{\int_{x=0}^{m} RR_{oa}(x)\,P_{as}(x)\,dx - \int_{x=0}^{m} RR_{oa}(x)\,P'_{as}(x)\,dx}{\int_{x=0}^{m} RR_{oa}(x)\,P_{as}(x)\,dx}$$

Where: *Pas(x)* and *P'as(x)* are the UPF intake distributions at the baseline and in the counterfactual scenario. *RRoa(x)* is the RR as a function of UPF participation in the energy of the diet specific for outcome (*o*) and age.

The model used estimates and uncertainties of number of disease events (deaths, incidences, and DALYs) in Brazil during 2019 from the Global Burden of Disease Study (30) (**Supplementary Tables 2–4**). The averted number of new cases of CHD and stroke was computed by multiplying an age, sex, and cause-specific PIF by the baseline number of events for the same sex and age stratum (**Supplementary Tables 2–4**). The total numbers of new CVD events averted were calculated as the sum of estimates over all strata and we summed CHD and stroke estimates to generate estimates for total CVD.

The outcomes for individuals with less than 30 years of age were excluded because most CVD events occur among adults after this age threshold. Events among individuals over 70 years of age were also excluded to account only for the premature (preventable in principle) CVD deaths, incidence, and DALYs attributable to UPF intake (34).

TABLE 1 Comparative risk assessment model input parameters to estimate the burden of cardiovascular diseases attributable to the consumption of ultra-processed foods in Brazil, 2019.

Model inputs	RR	Source
Baseline characteristics		
Population count (by age and sex)		Brazilian Population Estimates (29)
Deaths, incident cases and DALYs (by age and sex)		Global Burden of Disease Study (GBD) (30)
Ultra-processed food intake (by age and sex)		Brazilian Dietary Survey 2017-2018 (16)
Ischaemic heart disease	1.29 (1.12-1.48)	Pagliai et al. (4)
Stroke	1.34 (1.07-1.68)	Pagliai et al. (4)

RR, relative risks; DALYs, disability adjusted life years.

The model also incorporated probabilistic sensitivity analyses using a Monte Carlo approach for estimating the uncertainty of different model parameters and population heterogeneity to be propagated to the outputs using the Ersatz program (*n* = 5,000) (35, 36). For each simulation, the simulation works through producing a draw from the distributions of (a) baseline participation of UPF intake in the energy of the diet, (b) prevalence and incidence of CHD and stroke in each stratum, (c) the RR of UPF intake and CHD and stroke outcomes, (d) the current number of events (deaths, incident cases, and DALYs) for each outcome. Each set of draws from the Monte Carlo analyses were incorporated in the estimated PIFs and averted events of each outcome for each age-sex stratum so results were reported for the median and the 95% uncertainty intervals (UI) and rounded to the nearest hundred.

Finally, the robustness of the model was assessed through deterministic sensitivity analyses, by changing key model assumptions and inputs. We evaluated the impact of higher minimum theoretical and higher and lower maximum UPF intake thresholds for the RR parametrization (10.0% ± 4.1% and 12.0% ± 5.0% or 20.0% ± 8.2%and 24.0% ± 10.6%, respectively). Lastly, we explored lower and higher RR for UPF intake and CVD outcomes (10% differences) than estimated in the primary model.

Results

In 2019, a total of 88,438 Brazilian adults aged 30 to 69 years died prematurely from the major CVD (ischaemic heart disease and stroke). The contribution of ultra-processed foods to total energy intake of Brazilian adults decreases tended to decrease with age, for both men and women, and ranged from 13% to 21% of the total energy intake (**Supplementary Table 3**).

We estimated that approximately 19,200 premature deaths (95% UI, 7,097 to 32,353), 74,900 new cases (95% UI, 25,983 to 128,725), and 883,000 DALYs/year (95% UI, 324,279 to 1,492,593) from CVD were attributable to the consumption of UPF in Brazil in 2019 (**Table 2**), corresponding to, approximately, 22% of the premature CVD outcomes and one third of the deaths from all causes attributable to UPF.

Considering all premature deaths from CVD attributable to UPF, 59% were from ischaemic heart disease and 56% were among men. Approximately 54% of the premature incident cases of CVD attributable to UPF were from ischaemic heart disease and mostly among women (57%). Finally, 58% of the DALYs attributable to UPF intake were from ischaemic heart disease and, also, mostly among men (54%).

We estimated that a 10% reduction in the energy participation of UPF in the diet would avert 11% of all premature CVD events attributable to UPF (**Figure 1**), i.e., approximately, 2,100 deaths (95% UI, 697 to 4,511), 8,100 incident cases (95% UI, 1,413 to 8,047), and 96,400 DALYs (95% UI, 31,924 to 209,133) from CVD in 2019. A 20% in the energy participation of UPF would avert 21% of the premature CVD events attributable to UPF, i.e., approximately, 4,100 deaths (95% UI, 1,413 to 8,047), 16,200 incident cases (95% UI, 5,130 to 32,100), and 191,400 DALYs (95% UI, 65,127 to 374,968) from CVD in 2019. A 50% reduction in the energy participation of UPF in the diet is expected to prevent 52% of the premature CVD events attributable to UPF, corresponding to, approximately, 9,900 deaths (95% UI, 3,682 to 17,820), 38,900 incident cases (95% UI, 13,399 to 70,951), and 460,400 DALYs (95% UI, 168,345 to 830,583) from CVD in 2019. Finally, if the Brazilian population's UPF consumption was reduced to that of the first quintile of the baseline scenario, some

TABLE 2 Estimated burden of ultra-processed foods on cardiovascular disease events among Brazilian adults from 30 to 69 years of age (deaths, incident cases and DALYs) in 2019.

Metric and disease	No. of events averted (95% UI)		
	Men	Women	Total
Deaths/year			
Total CVD	10,700 (4,735-16,752)	8,500 (2,361-15,601)	19,200 (7,097-32,353)
Ischaemic heart disease	6,900 (3,025-10,829)	4,500 (1,276-8,391)	11,400 (4,301-19,220)
Stroke	3,800 (1,710-5,923)	4,000 (1,085-7,209)	7,800 (2,795-13,133)
Incident cases/year			
Total CVD	31,900 (14,153-50,056)	43,000 (11,830-78,669)	74,900 (25,983-128,725)
Ischaemic heart disease	19,800 (8,724-31,232)	20,600 (5,757-38,087)	40,400 (14,481-69,319)
Stroke	12,100 (5,429-18,824)	22,300 (6,073-40,582)	34,400 (11,502-59,406)
DALYs/year			
Total CVD	479,300 (212,972-752,662)	403,700 (111,306-739,931)	883,000 (324,279-1,492,593)
Ischaemic heart disease	308,700 (136,439-486,890)	205,700 (57,498-380,410)	514,400 (193,937-867,300)
Stroke	170,600 (76,533-265,772)	198,000 (53,808-359,521)	368,600 (130,342-625,293)

CVD, cardiovascular disease; UI, uncertainty intervals; DALYs, disability adjusted life years.

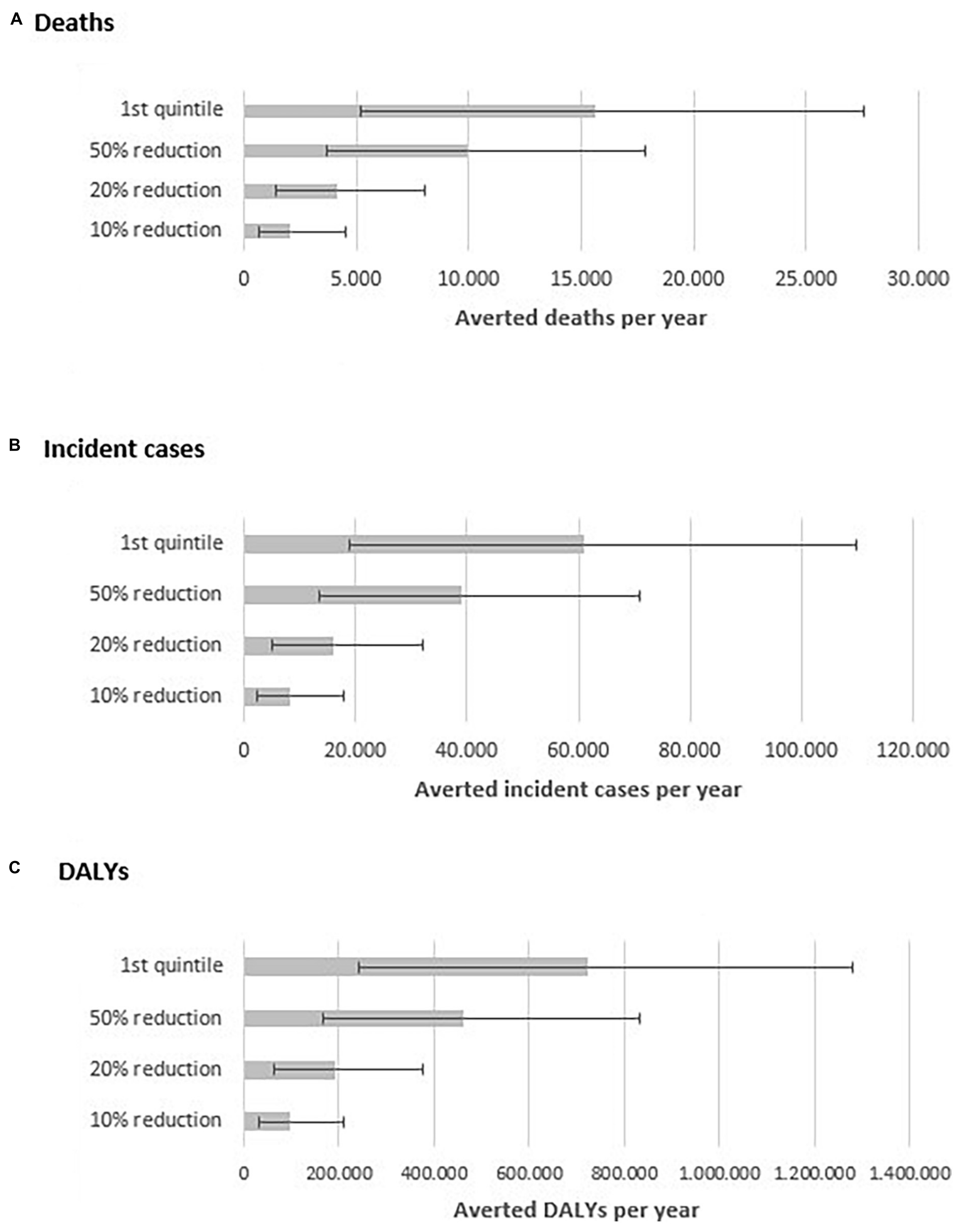

FIGURE 1
Estimated number of averted premature deaths **(A)** incident cases **(B)** and DALYs **(C)** per year by scenario of reduction of ultra-processed food intake in Brazil.

15,600 premature deaths (95% UI, 5,229 to 27,519), 60,900 new cases (95% UI, 18,816 to 109,779), and 722,500 DALYs (95% UI, 239,993 to 1,279,187) from CVD would be averted in 2019.

Sensitivity analyses

Considering the five different sensitivity analysis scenarios the modelled estimates of CVD events attributable to the consumption of UPF varied from -10.6% (10% higher RR) to +4.8% (12% higher minimum theoretical risk) compared to the primary model estimate. Other sensitivity analysis scenarios had relatively minor impact on the modeled estimates compared to the primary model (**Supplementary Figure 1**).

Discussion

Based on this modeling study, the consumption of UPF is associated with a significant CVD burden in Brazil, contributing to about 22% of the premature CVD events or approximately 19,200 premature deaths, 74,900 incident cases and 883,000 DALYs in 2019. The premature CVD deaths attributable to UPF intake also represent 34% of the attributable all-cause deaths to UPF (25). Additionally, if UPF intake was progressively reduced by 10% up to 50%, we estimated that attributable CVD events would be reduced by 11 to 52%, and, if consumption was reduced to that of the first quintile of UPF distribution at the baseline (2017-2018), approximately 81% of the attributable CVD events would be averted.

Most previous modeling studies in Brazil and in other countries have estimated the CVD burden of specific-dietary factors associated with critical nutrients (37–41). Nevertheless, UPF intake is associated with disease outcomes, including CVD, independently of their low nutritional composition (excessive sodium, fat and sugar content) (42), so new modeling studies designed specifically to assess the impact of industrial food processing on health outcomes are needed. The association between the consumption of UPF and CVD has been evidenced by prospective cohort studies in different countries (32, 33, 43–45) and more recently in systematic reviews and meta-analyses (4–6). The effects of UPF on CVD and other cardiometabolic risk factors is likely mediated through biological mechanisms related to poor nutritional dietary quality, food additives, changes in the physical structure of foods, and other attributes of these foods that may affect health by altering serum lipid concentrations and causing inflammation, oxidative stress, dysglycemia, insulin resistance, and hypertension, among other outcomes (42). Therefore, this study has estimated the association between dietary patterns and CVD events, by incorporating the potential impacts of nutrients, food additives and industrial food processing on cardiovascular health that are not captured by other models (46).

In Brazil, as in many other low and middle-income countries, traditional fresh and minimally processed foods have been replaced by ready-to-(h)eat UPF over the last two decades (16, 47). Although there are few studies on the estimated impact of these dietary changes, our previous study estimated that if UPF intake increase by around 50% (to intakes similar to those of Mexico), the all-cause attributable deaths would almost double, while if UPF intake tripled (to the intakes equivalent to those in the United States), the attributable deaths would be increased by 250% (28). Also, other study has estimated that the impact of different reduction scenarios for saturated and trans fats, salt and added sugar from culinary ingredients, processed and ultra-processed foods could avert from 37.6 to 196.4 thousand deaths from CVD in Brazil, in 2,048 (24).

UPF intake is an important dietary risk factor that must be addressed through individual and populational preventive strategies such as changing food environments, strengthening the implementation of food-based dietary guidelines, and improving consumer knowledge, attitudes, and behaviour. Individual-level dietary strategies to change behavioral risk factors are very limited. Therefore, it is key for public policies to promote healthy food environments to reduce the intake of ultra-processed foods, considering the need to incentive the consumption of fresh and minimally processed foods and to discourage UPF intake, through fiscal and regulatory policies. These policies may include the regulation of food publicity, the regulation of sales of unhealthy foods in school and work environments, the implementation of front of package nutritional labeling, subsidies to the production and commercialization of fresh local foods, and through the taxation of UPF (48–51). For example, in Chile, the purchase of foods high in calories declined by 23.8% after the implementation of the front of package nutritional warnings (52). In Mexico, sugary beverage consumption was reduced by 6.3% after a 10% tax to sugar-sweetened beverages (53).

Particularly in the national context, the Dietary Guidelines for the Brazilian Population play an important role in nutritional public policies, by recommending diets based on natural or minimally processed and avoiding the consumption of UPF (17). These recommendations must be implemented considering both individual and populational strategies and must guide health sector and intersectoral policies for healthy diet promotion. After Brazil, several countries and international organizations have adopted dietary guidelines based on the extension and purpose of food processing (54–56).

Strengths and limitations

Comparative risk assessment models are well acknowledged ex ante evaluation tools for estimating the burden of dietary risk factors an to assess potential food policy implementation scenarios, that have been validated in literature and adapted to different country contexts (38, 57–59). Based on these methods, recent robust meta-analysis studies have provided estimates of the RR of UPF intake and several health outcomes, allowing the development and validation of the first modeling studies to assess the impact of dietary patterns based on the extent and purpose of food processing (25).

Additionally, the modeled data inputs nationally representative (demographic and food consumption data) and based on deaths, incident cases and DALYs were obtained from validated estimates from the GBD Study for Brazil (30). In particular, the UPF intake data was obtained from a nationally representative sample, based in two non-consecutive 24-h food recalls with strong quality control protocols (16). Finally, the RR used in the model were obtained from the recent meta-analysis based on cohort studies in various countries (4).

There are several limitations that should be considered when interpreting our results. First, we assumed the portability of the pooled RR, which were based on cohort studies from other countries, to estimate the PIF for Brazil (60). Second, we can not exclude the possibility of residual confounding in these RR estimates. In order to overcome part of these limitations, we incorporated the uncertainties of the RR estimates and of other data inputs in the model through Monte Carlo simulations (61). Third, comparative risk assessment models, when compared to dynamic modeling approaches, do not incorporate a timeframe properly, so they are not intended to estimate the projected future impacts of changes in the risk factors and do not consider the possible time lag between changes in risk exposure and disease outcomes. Finally, comparative risk assessment models do not account for recurring events and do not consider the influence of interactions between individuals, populations or their environments and the potentials health equity impacts. This model allows a comparable and consistent estimation of premature CVD events attributable to the consumption of UPF that can be applied to different contextsto estimate the population health impact of changes in the diets. Therefore, the model represents a helpful tool for researchers and policymakers to understand the impact of dietary patterns on health outcomes and to develop and assess context-specific prevention policies. Of note, our study was concentrated solely on estimating the impact of UPF intake on CVD outcomes. Future modeling studies must also include other disease outcomes associated to UPF, such as obesity, diabetes, and cancers, in order to better estimate the overall health burden of industrial food processing and support policies for improving the food environment.

Conclusion

UPF intake is associated with an important CVD burden in Brazil. We estimated that, approximately, one third of the CVD events per year are attributable to the consumption of UPF in the country. This study provides evidence regarding the overall impact of industrial food processing on preventable CVD outcomes, supporting the Brazilian Dietary Guidelines, especially by avoiding the consumption of UPF. Our findings suggest that reducing UPF consumption should be a food policy priority within the strategies for improving cardiovascular health, achieving population health gains, and reducing preventable CVD events in Brazil.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

EN, ML, and LR conceived the idea and contributed to the design of the work. EN developed and validated the comparative risk assessment model and drafted the first draft of the manuscript. EN and ML contributed to the acquisition, analysis, and interpretation of data for the work. All authors have reviewed the draft manuscript and approved the final document.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1043620/full#supplementary-material

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EDITED BY
Gustavo Cediel,
University of Antioquia, Colombia

REVIEWED BY
Muhammad Nadeem,
University of Veterinary and Animal Sciences, Pakistan
Daniel Henrique Bandoni,
Federal University of São Paulo, Brazil

*CORRESPONDENCE
Juliana Rombaldi Bernardi
juliana.bernardi@ufrgs.br

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Complementary feeding methods and introduction of ultra-processed foods: A randomized clinical trial

Paula Ruffoni Moreira[1,2,3], Leandro Meirelles Nunes[1,3], Elsa Regina Justo Giugliani[1,3], Erissandra Gomes[4], Jordana Führ[1,3], Renata Oliveira Neves[1,3], Christy Hannah Sanini Belin[1,3] and Juliana Rombaldi Bernardi[1,2,3]*

[1]Hospital de Clínicas de Porto Alegre (HCPA), Porto Alegre, Brazil, [2]Graduate Program in Food, Nutrition, and Health, Department of Nutrition, School of Medicine, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, [3]Graduate Program in Child and Adolescent Health, Department of Pediatrics, School of Medicine, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, [4]School of Dentistry, Department of Surgery and Orthopedics, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil

Introduction: Complementary feeding (CF) is defined as a period when foods, other than milk, are introduced to the infant's diet. Unfortunately, frequent consumption of ultra-processed foods (UPF) has become highly prevalent early in an infant's life. The aim was to verify the association of CF methods with the introduction of UPF in early childhood.

Methods: This randomized clinical trial involved pairs of mother-infants, allocated in groups receiving different CF interventions: strict Parent-Led Weaning (PLW); strict Baby-Led Introduction to SolidS (BLISS), or mixed-method. The intervention consisted of a counseling session on healthy eating at the child's 5.5 months of age. A structured questionnaire was created based on the NOVA classification for the definition of UPF and applied at 9 and 12 months. The effect of the CF method intervention was measured by a survival curve for UPF offered for the first time in early childhood between groups. Cox regression was used to estimate its magnitude. The primary analysis was done in three groups (PLW, BLISS, and Mixed) and the secondary analysis was done in two groups (PLW, and BLISS + Mixed).

Results: A total of 139 mother-infant pairs were eligible and 129 followed the study. The prevalence of infants who were exposed to UPF in early childhood was 58.9% (n = 76), being 71.4% in the PLW group, 53.3% in the BLISS group, and 52.4% in the Mixed group, without differences between them (p = 0.133). The PLW group intervention had a greater chance of exposure to ice cream or popsicles (p = 0.032) and sweet crackers (p = 0.009), compared with the other two CF groups. The Cox regression did not find significant differences between the three groups. However, the regression with two groups estimated a 38% reduction in the offer of UPF in the BLISS + Mixed group intervention (p = 0.049).

Discussion: The CF intervention promoting greater infant autonomy (BLISS and Mixed) was associated with a reduction in the offer of UPF in early childhood. This knowledge may contribute to supporting strategies aimed at reducing UPF consumption by the young infant.

Brazilian registry of clinical trials (ReBEC): [https://ensaiosclinicos.gov.br/rg/RBR-229scm], identifier [RBR-229scm U1111-1226-9516].

KEYWORDS

complementary feeding, nutrition, complementary foods, nutritional interventions, child nutrition, randomized clinical trial

Introduction

According to the World Health Organization (WHO), complementary feeding (CF) is recommended when breast milk is no longer sufficient to meet the nutritional requirements of infants, and therefore other foods and liquids are needed, along with breast milk (1). The process, generally between 6 and 23 months of age, represents the transition from milk feeding to family foods (2, 3).

Usually, at the beginning of CF, children receive mashed foods offered with a spoon by an adult (4). This method of feeding is also called Parent-Led Weaning (PLW) and is majority guided by the adult that is offering the food. However, in the last decades, new methods of CF have been proposed, such as Baby-led Weaning (BLW) and Baby-led Introduction to SolidS (BLISS). Both advocate the introduction of unprocessed and minimally processed foods in a way that infants can put the food in their mouths by themselves (5, 6). These infant-guided methods seem to be beneficial by reducing infant food fussiness, increasing satiety responsiveness, and encouraging infants to improve their oral motor skills (7).

The ultra-processed foods (UPFs) are industrial formulations that typically include substances not commonly used in culinary preparations, and additives whose purpose is to imitate the sensory qualities of unprocessed foods (8), which included: soft drinks; packaged snacks and candies; mass-produced packaged bread and buns, cookies, pastries, cakes; margarine and other spreads; breakfast cereals; pre-prepared meat, cheese, pasta, and pizza dishes; poultry and fish nuggets and sticks; sausages, burgers, hot dogs, among other foods marketed (9).

The offer of UPFs is present in the diet of 43.1–90.6% of children under 24 months of age in Brazil (10, 11), and 53.7–91.2% in other populations (12). The most consumed UPFs among Brazilian children are artificial juice (nectar, concentrated drink, or refreshment), yogurt/dairy drink, soda, Petit-Suisse, crackers/biscuits, instant noodles, sweets (candies), and chocolate milk (13). Recent literature reviews confirmed that UPF consumption is associated with poor dietary quality and with adverse metabolic and health outcomes throughout life (14, 15). Longitudinal studies about its consumption at preschool age found a significant association with a higher increase in total cholesterol and Low-Density Lipoprotein (LDL) cholesterol (16), a significant increase in waist circumference from preschool to school age (17), and greater increases in adiposity from childhood to early adulthood (18).

Despite the increasing popularity and adherence to new methods of CF, there are few studies evaluating the impact of these methods on the introduction of unhealthy foods or UPFs (19, 20). The available data suggest that children feeding by BLW and BLISS methods have lower use of salt and sugar added, common ingredients in UPF (21). Given this scenario of the high consumption of ultra-processed foods in young children, strategies are needed to reduce this consumption. For this, it is necessary to know practices and behaviors associated with greater or lesser consumption of these foods.

In this context, this study aimed to verify whether interventions on different methods of complementary foods are associated with the introduction of UPFs in the diet of young children.

Materials and methods

Study design

This is a randomized clinical trial comparing three different groups of infants regarding the method of food introduction: strict Parent-Led Weaning (PLW): an approach conducted by the caregiver in which children are mostly spoon-fed; strict BLISS: a technique guided by the child, in which they feed themselves–there are no spoon-feeding or purees; mixed-method (Mixed): a combination of PLW and BLISS, according to the child's wishes for each food preparation, i.e., parents were instructed to initially apply the BLISS approach. If the child was not satisfied or showed disinterest, they were instructed to offer the food using the PLW technique during the same meal. The randomized clinical trial was designed to identify differences in health outcomes between groups (22, 23).

Participants

The sample was recruited by an online invitation, through social networking pages, targeted to mothers' groups, through newspaper ads, and on a Southern Brazil hospital bulletin board, between the years 2019 and 2020. An email address and a phone number were provided for interested mothers to make the first contact with the researchers showing interest in participating. At this moment, a standardized text explaining the intervention, household visits, and the need to commute to the hospital at 12 months of the children's age was given, in addition to verifying whether the child met the inclusion criteria (healthy singleton infants with birth weight greater than >2.500 grams and gestational age ≥37 weeks, internet access, living in Porto Alegre, RS, Brazil, or nearby cities and should not have started CF yet).

After checking the inclusion criteria, the mothers signed the free and informed consent form online. Behind signing, the participants were sequentially numbered and had their identification numbers entered into a randomization list of three blocks and equal numbers, previously computer-generated[1] by a blinded researcher, that did not have contact with the participants during the recruitment or the data collection. Participants were enrolled and assigned by different study group researchers.

Intervention

The detailed intervention, performed at 5.5 months of children's age, was published previously (22, 23). Briefly, it consisted of a dietary workshop, carry out at a private nutrition office equipped with a test kitchen, in which a nutritionist cooked in real-time examples of baby food and explained standardized information about the CF method to the participants, that were blind to the allocation group until the intervention day. The nutritionist was previously informed about what method she would teach, and the blindness was guaranteed with a different researcher contacting the participants. Regardless of the allocated group, the dietary workshop promoted healthy eating, based on the "Dietary Guidelines for Brazilian Children Under Two Years of Age," by the Ministry of Health of Brazil (4). It consists in offering mostly unprocessed or minimally processed foods, with a minority offer of culinary ingredients and processed foods; being the offer of UPF discouraged.

Parents were encouraged to offer fruits as snacks during the first year of life and stimulated to postpone the use of ready-to-eat meals. Freezing techniques were also taught as an alternative to reduce the preparation time of dinner and lunch meals. At the end of the intervention, an illustrated pamphlet was given summarizing the information and listing examples of UPF that should not offer before 2 years of age. The nutritionist's phone number and email address were available to the family during the first 12 months of the child, to provide any extra support needed or to report adverse events.

Data collection

Sociodemographic (maternal age, family income, maternal education, marital status, parity, and child's sex) variables were collected through a questionnaire sent online to the mothers after signing the free and informed consent form.

In two moments, at nine and 12 months of age, a structured questionnaire about the offer of UPF was applied to ask if the mother had ever offered any UPF from a list and, if positive, how old the child was at the moment of this first exposure (**Supplementary material**). Likewise, the parents answered questions about exclusive breastfeeding (EBF), any breastfeeding (BF), and CF introduction.

Because of the COVID-19 pandemic, initiated in March 2020, presential collections were suspended, and questionnaires were answered online at 9 months by 50.7% (n = 67) mothers, and after 12 months by 80.3% (n = 94), between March 2020 and March 2021.

Exclusive breastfeeding practice was defined as when the child received no liquid or solid other than human milk–not even water–except the oral rehydration solution, or drops/syrups of vitamins, minerals, or medications. Any BF practice was defined as receiving any amount of human milk by bottle, cup, or breast, independent of any other food offering (24).

Foods were categorized according to the degree of food processing using the NOVA classification (9, 25, 26), which defines UPF as products with multiple ingredients and stages of processing techniques, many of them exclusively for industrial use. The authors listed the most frequently consumed products during childhood. This list was created based on the most popular consumed products in this period of life according to the "Dietary Guidelines for Brazilian Children Under Two Years of Age" (4), which comprehended: chocolate milk, soft drinks, industrialized baby food, processed meat, sandwich cookies, sweet crackers, salty snacks, chocolate, candies, gelatin, ice cream or popsicle, and artificial juice.

Sample size

The sample size was calculated by the online version of Power and Sample Size for Health Researchers (PSS Health®,

1 www.randomization.com

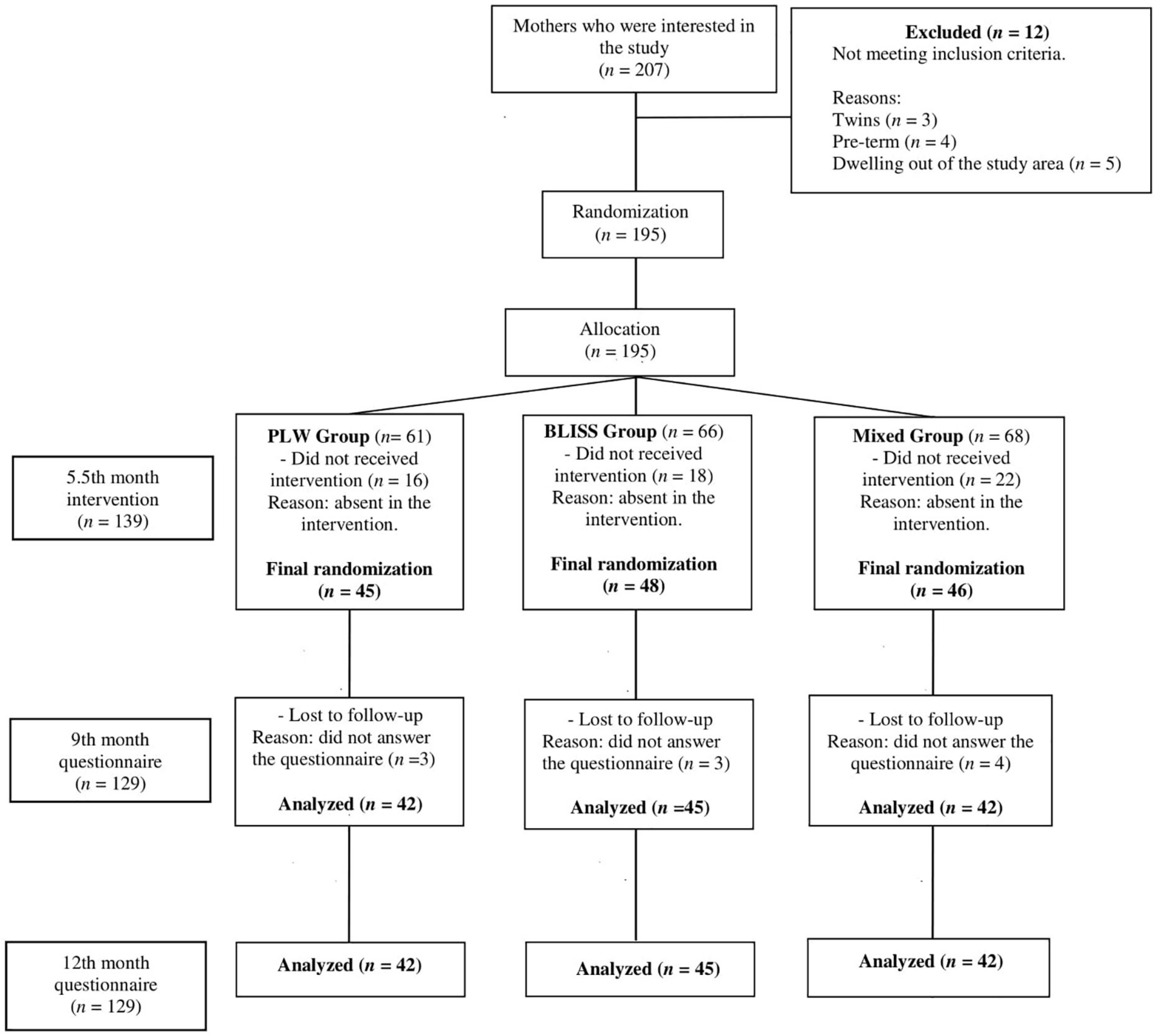

FIGURE 1
Study design flow chart, Brazil, 2019–2021. PLW, parent-led weaning; BLISS, baby-led introduction to solids.

Porto Alegre, Brazil) to detect a difference in the exposure to UPF offer of 30% (27). For a power of 80% at a significance level of 5%, based on two-sided testing, including 5% of patients lost to follow-up, the estimated minimum sample size was 132 patients (42 per group).

Statistical analysis

The database was created using double data entry. Statistical analyses were performed using the software Statistical Package for the Social Sciences® (SPSS, Inc., Chicago, IL, USA) version 22.0 for Windows. The statistical analyses were based on the intention to treat principle. Qualitative variables were expressed by absolute number and percentage, and non-parametric quantitative variables were expressed by the median and interquartile range [P25–P75]. For comparisons, ANOVA one-way test with Tukey's *post-hoc* was used, as well as the Kolmogorov–Smirnov test to identify the normality of variables.

The survival analysis was used to compare the frequency of initiation of UPF offers in the first 12 months of life between the different groups. The log-rank test was applied to compare the Kaplan–Meier curves, and Cox regression was applied to estimate the magnitude of the association between the intervention and the introduction of UPF in the first year of life, through hazard ratio (HR) and its respective confidence interval (CI) of 95%. The medians of the children's age at which UPF was introduced for the different groups and respective 95% CI, expressed in days, were also calculated. The statistical significance level adopted was $p < 0.05$.

Initially, the results are presented as a 3-arm trial, as proposed in the protocol of the study; however, to compare the effect of the intervention on UPF offer, the methods

TABLE 1 Characteristics of mothers and infants according to interventions groups, Brazil, 2019–2021.

Characteristics *n* (%)	Total 129 (100.0)	PLW 42 (32.6)	BLISS 45 (34.8)	Mixed 42 (32.6)
Mothers' characteristic				
Maternal age (years), median [P25-P75]				
	34 [30–37]	34 [27–37]	35 [32–39]	33 [29–36]
Parity, *n* (%)				
Primiparous	106 (82.2)	32 (76.2)	36 (80.0)	38 (90.5)
Family income (BRL), median [P25-P75][a]				
	6.250 [4.000–10.000]	5.000 [3.250–10.000]	8.000 [4.000–14.000]	5.500 [3.875–10.000]
Maternal education (years), median [P25-P75]				
	18 [15–20]	16 [13–20]	18 [15–20]	18 [16–20]
Live with a partner, *n* (%)				
Yes	110 (85.3)	33 (78.6)	41 (91.1)	36 (85.7)
Race/ethnicity, *n* (%)				
White	109 (85.2)	34 (82.9)	38 (84.4)	37 (88.1)
Infants' characteristic				
Sex, *n* (%)				
Female	66 (51.2)	24 (57.1)	23 (51.1)	19 (45.2)
EBF (up to the 6 months), ***n* (%)***				
Yes	78 (62.4)	25 (64.1)	25 (55.6)	28 (68.3)
Any BF (at 12 months), ***n* (%)**				
Yes	101 (78.3)	35 (83.3)	35 (77.8)	31 (73.8)

BLISS, baby-led introduction to solids; PLW, parent-led weaning; EBF, exclusive breastfeeding; BF, breastfeeding; P, percentile; *n = 125. Family income expressed in BRL (Brazilian Real)–[a]1 BRL = USD 0.21.

that promote greater autonomy (BLISS and mixed) (28) were combined into a single group, because they have similar outcomes in the survival curves and to increase the power of the statistical analysis.

Ethical aspects

The research was approved by the Research Ethics Committee of the Hospital de Clínicas de Porto Alegre under number 2019-0230 (CAAE: 1537018500005327). The clinical trial was submitted to the Brazilian Registry of Clinical Trials (ReBEC), under number RBR-229scm U1111-1226-9516.

Results

A total of 207 mother-infant pairs contacted the research team, out of which 12 (5.8%) did not meet the inclusion criteria, leaving 195 mother-infant pairs eligible that were randomized. There were 56 (27.0%) mother-infant pairs who chose not to proceed with the interventions. A total of 139 mother-infant pairs were included in the study, 45 (32.4%) in the PLW group, 48 (34.5%) in the BLISS group, and 46 (33.1%) in the mixed-method group. During the follow-up, 10 mother-infant pairs failed to answer the questionnaires. Finally, data from 129 mother-infant pairs were analyzed in the study. Harms or unintended effects were not reported by participants. The clinical trial profile is shown in Figure 1, from the recruitment of the mother-infants pairs until the evaluation in the 12 month of children's age.

The characteristics of the mother-infant pairs included in the study are shown in Table 1. There are no statistically significant differences in these variables between intervention groups ($p \geq 0.05$).

The prevalence of infants who were offered at least once UPF in the first year of life was 58.9% (n = 76): PLW group 30/42, 71.4%, BLISS group 24/45, 53.3%, and mixed group 22/42, 52.4%, without statistically significant differences between groups ($p = 0.133$) (data not shown in tables).

The median age of offer to UPF was 300 days [240–365] in the PLW group, 365 days [240–365] in the BLISS group, and 365 days [270–365] in the mixed group. There are no statistically significant differences between the three methods and the age of offer to UPF ($p = 0.086$). Analyzing the PLW group versus the BLISS and Mixed groups together, 300 days [240–365] and 365 days [270–365], respectively, there is a statistically significant difference to offer later in the groups in which the children had greater autonomy ($p = 0.037$) (data not shown in tables).

The offer of each UPF item between groups is shown in Figure 2. The PLW group had a significantly more chance of exposure to children to ice cream or popsicles ($p = 0.032$) and

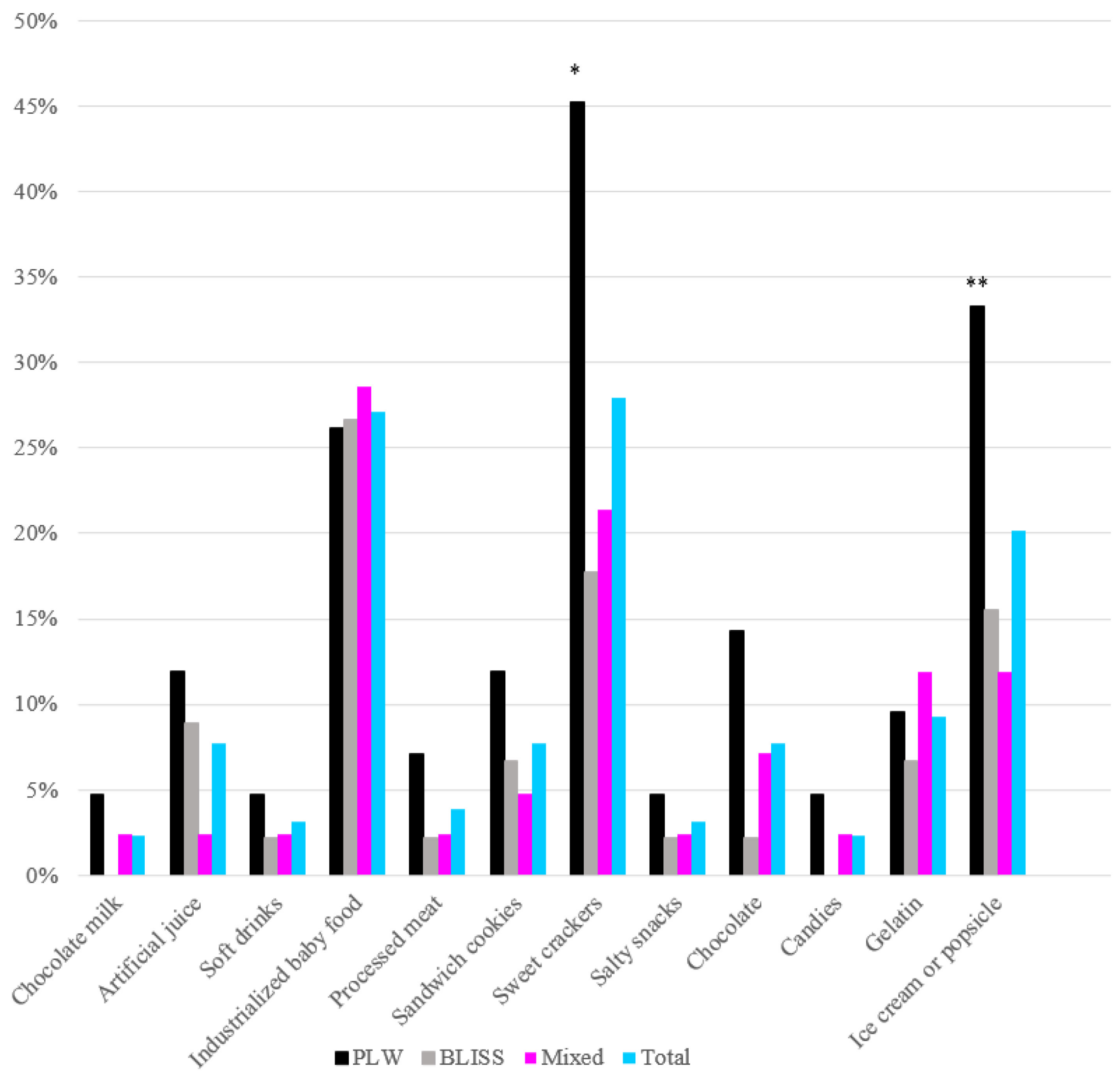

FIGURE 2
Prevalence of ultra-processed food offered in the first year of life according to interventions: PLW, BLISS, and mixed groups, Brazil, 2019–2021. PLW, parent-led weaning; BLISS, baby-led introduction to solids. *$p < 0.05$; **$p < 0.001$.

sweet crackers ($p = 0.009$), compared with the other two CF groups.

Figure 3 shows the Kaplan–Meier curves of the initiation of UPF offer to children according to the CF intervention: BLISS, PLW, and Mixed groups. The log-rank test indicated that the curves were not significantly different between the groups ($p = 0.104$). However, by grouping the BLISS and mixed intervention groups the log-rank test indicated that the curves were significantly different between the groups ($p = 0.035$) (Figure 4).

The Cox regression did not find differences between the PLW (control) and the BLISS (HR 1.53; 95% CI 0.89–2.63; $p = 0.118$) and mixed (HR 0.93; 95% CI 0.52–1.66; $p = 0.808$) groups individually. However, by agreeing on the BLISS and mixed intervention methods (two interventions promoting more autonomy for children to eat), the Cox regression estimated a 38% reduction in the UPF offer (HR 0.62; 95% CI 0.39–0.99; $p = 0.049$) (Table 2).

Discussion

In this study, children randomized to intervention groups promoting greater autonomy to eat (BLISS and Mixed), were exposed to UPF 65 days after those randomized to the PLW method intervention. Being allocated to BLISS and Mixed groups interventions reduced 38% of the UPF offer in early childhood. The early introduction of UPF, with high-sugar and hyper-palatable foods, can cause taste dysfunctions in early childhood. Children are born with a biological predisposition

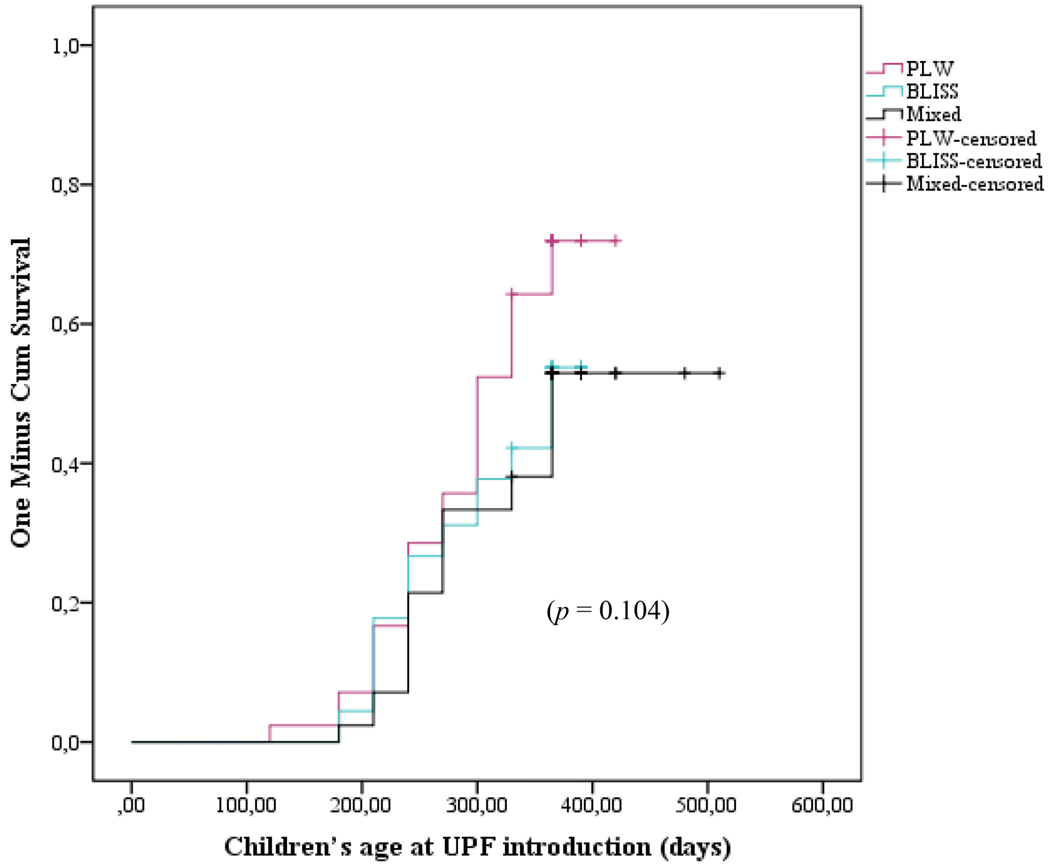

FIGURE 3
Kaplan–Meier curve displaying the probability of being introduced to ultra-processed foods in the first year of children's life according to interventions: PLW, BLISS, and mixed groups, Brazil, 2019–2021. PLW, parent-led weaning; BLISS, baby-led introduction to solids.

to prefer sweets, probably an evolutionary adaptation to be attracted to foods rich in energy (carbohydrates) (29). Thus, the posterior exposure among those allocated in BLISS and Mixed methods can be protective concerning the formation of the infant taste.

Even after the intervention on healthy CF and the recommendation not to offer UPF before 24 months, more than half of the children were exposed to UPF in early childhood (58.9%). One study conducted in Brazil demonstrated a prevalence of 31.3% of exposure to UPF in children under 6 months, a period in which the recommendation is for dairy feeding exclusively (30). Another Brazilian study with children under 1 year showed that 87.5% had been exposed to at least one UPF the day before (31). In general, the consumption of UPF is associated with conditions of economic vulnerability (32). However, despite the high income and schooling of the mothers in this sample, we found a high prevalence of exposure to this type of food. In this randomized clinical trial, no differences were found in the income and schooling of randomized mothers for the PLW method intervention that explained the higher and earlier exposure to processed foods.

A recent study in Portugal evidenced that most of the available foods on the market are industrialized and ultra-processed, and the consumption of these foods is greater in the higher-income neighborhood (27). This scenario is similarly found in Brazil (33). According to a recent cross-sectional study, more than 50% of products destined for children under 12 months are classified as UPF in the market, opposite to what Brazilian and international guidelines recommend for this age, making it crucial to implement innovative strategies for parents to improve the CF practices and disseminate correct information regarding food processing (34). A cross-sectional analysis found that 47% of mothers (n = 631) did not follow the infants' healthy eating recommendations received by public health providers. Out of these, 45.7% did not recognize the significance of food on child health even after the professionals' instructions. The authors of this research state that simply passing information to parents may not be enough to motivate mothers' actions regarding healthy eating habits (35).

Breastfeeding has been reported to reduce exposure to UPF (36, 37). Children who are breastfed develop a greater acceptance of the flavors present in vegetables, while non-breastfed children have a greater acceptance of sweets (38). So,

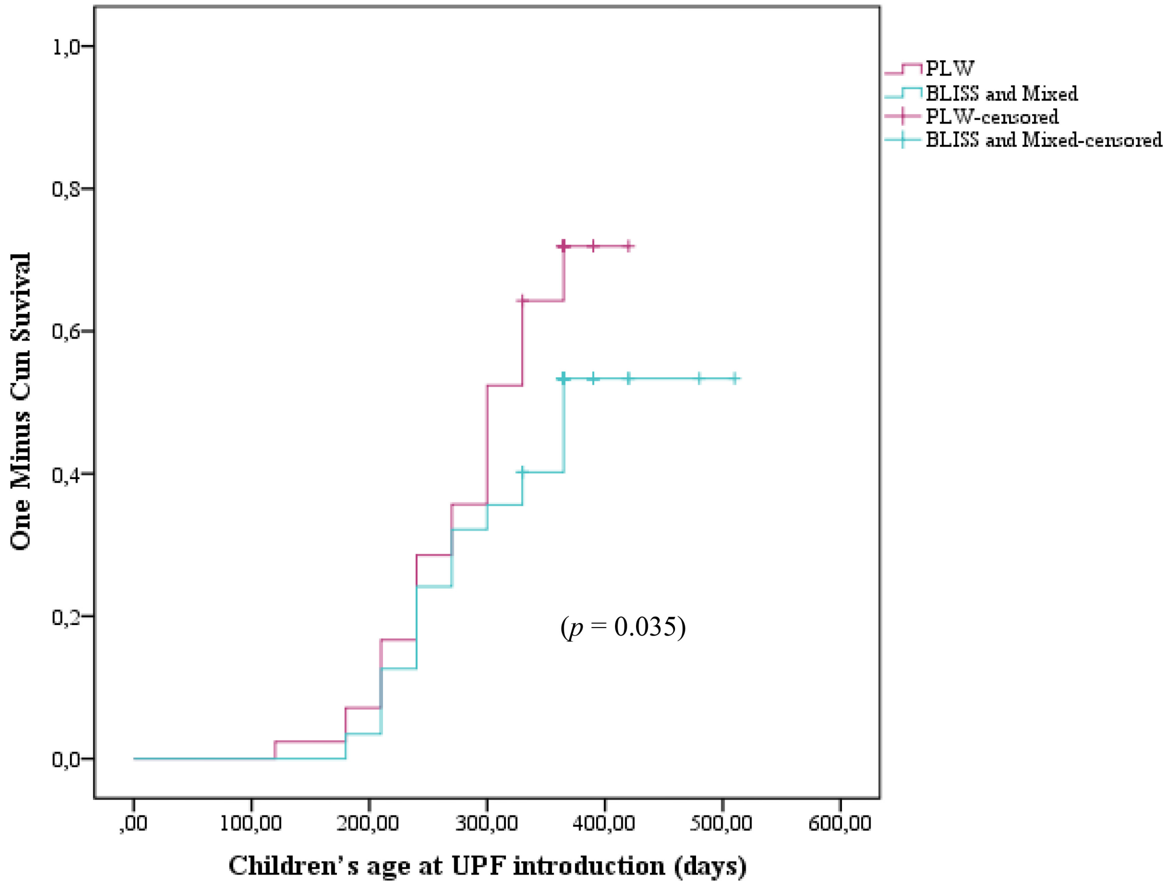

FIGURE 4
Kaplan–Meier curve displaying the probability of being introduced to ultra-processed foods in the first year of children's life according to interventions: PLW, BLISS, and mixed groups, Brazil, 2019–2021. PLW, parent-led weaning; BLISS, baby-led introduction to solids.

it is likely that the association between breast milk and UPF is partly due to differences in taste. We found high rates of BF in our sample; however, this did not seem to reduce exposure to UPF. Nevertheless, the effect of BF on UPF intake is not restricted to early childhood. A cohort study showed that BF for more than 4 months of age reduced calorie intake from UPF (39). Although we did not observe a reduction in the supply of UPF in a sample at a rate higher than 60% of EBF, BF should still be encouraged for better taste formation.

Belonging to the intervention groups with greater autonomy delayed the introduction of UPF by 4 weeks in our research. It is likely that the intervention of BLISS and Mixed methods, which promoted the benefits of the child eating whole and fresh foods, aroused in mothers an additional concern not to offer UPF. Additionally, the discouragement of the use of the spoon may have contributed to the lower exposure to ice cream, which may explain the greater exposure to this food in the PLW method. Although the question asked by the mothers did not specify whether the offer was ice cream or popsicle, ice cream was likely the most consuming food among those randomized to the PLW intervention group since this food should preferably be offered per spoon to the child. Another UPF most prevalently offered in the PLW method was sweet crackers, a food that usually children eat by hand. A possible explanation for this is that this type of food is wrongly considered practical to be offered to train children's autonomy in PLW groups, which is not necessary for other methods.

TABLE 2 Risk of exposure to ultra-processed foods (UPFs) in the first year of life, according to complementary feeding (CF) interventions groups, Brazil, 2019–2021.

Complementary feeding interventions	HR	CI	*P*-value
PLW	1		
BLISS	1.536	0.897–2.632	0.118
Mixed	0.931	0.522–1.660	0.808
BLISS and mixed	0.629	0.396–0.998	0.049*

PLW, parent-led weaning; BLISS, baby-led introduction to solids; HR, hazard ratio; CI, confidence interval; *$p < 0.05$.

It is important to note that this study occurred at a time when the new Brazilian infant food guideline was being implemented (40). Previously, the Brazilian infant guideline (4) did not focus heavily on the processing level of the foods offered, as the new guideline does, despite already endorsing healthy food choices. Thus, it is possible that, once the information in the new guideline is implemented and disseminated, the knowledge about UPF will increase and, consequently, their offer can decrease.

This study had limitations and strengths. Since our sample was spontaneously recruited mainly from on-target social networks, it could result in mothers previously interested in healthy eating. The change from in-person questionnaires to online could modify the responses and refer to different sociodemographic characteristics of our population. Furthermore, we did not measure the frequency of exposure of the children to UPF the infant in the first year. As the results were analyzed by the Intention-to-Treat statement, we couldn't measure adherence to the CF methods. However, it is noteworthy that our results constitute the first known publication exploring the consumption of UPF among three randomized groups submitted to a healthy eating intervention in early childhood, a period crucial to the establishment of healthy habits.

Conclusion

In conclusion, the infants who were submitted to the interventions using methods of introduction of CF with greater autonomy were less exposed to UPF and were exposed later. In addition, despite the intervention in healthy eating, it is high the prevalence of children exposed to UPF during the first year of life. Further studies are needed to confirm these findings and to explain the association and mechanisms involved with outcomes of child health. This knowledge may contribute to supporting strategies aimed at reducing UPF consumption by young children.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Research Ethics Committee of the Hospital de Clínicas de Porto Alegre under number: 2019-0230 (CAAE: 1537018500005327). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

LN, JB, and EG conceptualized and designed the study, drafted the initial manuscript, and revised the manuscript. ERJG reviewed the statistical analyses and the manuscript. JF, PM, and CB collected data and carried out the analyses. RN coordinated data collection and statistical analyses. All authors wrote and approved the final manuscript as submitted and agree to be accountable for aspects of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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EDITED BY
Fernanda Rauber,
University of São Paulo, Brazil

REVIEWED BY
Fabiola Suano-Souza,
Federal University of São Paulo, Brazil
Juliana Rombaldi Bernardi,
Federal University of Rio Grande do Sul, Brazil

*CORRESPONDENCE
Ida Henriette Caspersen
Ida.Henriette.Caspersen@fhi.no

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Ultra-processed food consumption and associations with biomarkers of nutrition and inflammation in pregnancy: The Norwegian Environmental Biobank

Pieta Tasnim Kelsey[1,2], Eleni Papadopoulou[3], Tiril Cecilie Borge[4], Cecilie Dahl[2], Anne Lise Brantsæter[1], Iris Erlund[5], Helle Margrete Meltzer[1], Line Småstuen Haug[1] and Ida Henriette Caspersen[6]*

[1]Division of Climate and Environmental Health, Department of Food Safety, Norwegian Institute of Public Health, Oslo, Norway, [2]Department of Community Medicine and Global Health, Institute of Health and Society, University of Oslo, Oslo, Norway, [3]Global Health Cluster, Division for Health Services, Norwegian Institute of Public Health, Oslo, Norway, [4]Cluster for Reviews and Health Technology Assessments, Division for Health Services, Norwegian Institute of Public Health, Oslo, Norway, [5]Department of Government Services, Finnish Institute for Health and Welfare, Helsinki, Finland, [6]Centre for Fertility and Health, Norwegian Institute of Public Health, Oslo, Norway

Background: A high consumption of ultra-processed foods (UPFs) is often associated with low nutritional quality, but data on associations with biomarkers are scarce. We aimed to explore associations between UPF intake, diet quality, and concentrations of biomarkers of nutrition and inflammation measured in mid-pregnancy.

Methods: This cross-sectional study included n = 2,984 pregnant women recruited during 2002–2008 in the Norwegian Mother, Father, and Child Cohort Study (MoBa). Concentrations of C-reactive protein (CRP) and 21 nutritional biomarkers including carotenes (α-carotene, β-carotene, γ-carotene, α-cryptoxanthin, β-cryptoxanthin, lutein, lycopene), vitamins [α-tocopherol, γ-tocopherol, 25-hydroxyvitamin D (25-OH-D), retinol], creatinine, elements (K, Na, Co, Cu, Mn, Mo, Se, Zn), and ferritin (Fe) were measured in blood and urine collected in mid-pregnancy. Habitual diet in pregnancy was assessed using a validated semi-quantitative food frequency questionnaire. We calculated the relative (%) energy contribution of UPF to overall intake according to the NOVA classification. We also applied a diet quality index (DQI) adapted to assess adherence to Norwegian dietary guidelines (DQI; min–max: 0–110, higher score meaning higher adherence). We present summary statistics for biomarker concentrations and explored associations between UPF intake or the DQI and measured biomarkers using adjusted linear, logistic, and generalized additive regression models.

Results: Ultra-processed food intake was positively associated with biomarker concentrations of vitamin E (γ-tocopherol), creatinine, K, and Na [βs: 5.6 to 17% increase in biomarker concentration per interquartile range (IQR) increase in UPF intake] and negatively associated with carotenoids (α-carotene, β-carotene, γ-carotene, α-cryptoxanthin, β-cryptoxanthin, lutein, lycopene), vitamin A, Mo, and Se (βs: −2.1 to −18%). Inversely, high diet quality (i.e., the DQI) was positively associated with concentrations of carotenoids, vitamins [vitamin A (retinol) and D (25-OH-D)], and Se (β: 1.5 to 25%) and negatively associated with vitamin E (γ-tocopherol), creatinine, and Na (β: −4.8 to −8.3%). A weak, positive association was found between UPF and CRP (β: 5.4%, 95% CI 0.12–11%).

Conclusion: High UPF intake was associated with reduced concentrations of nutrition biomarkers in mid-pregnancy. Associations in the opposite direction were found with high adherence to the Norwegian dietary guidelines, suggesting that the two dietary scoring systems capture diet quality in a mirrored manner in this population.

KEYWORDS

pregnancy, C-reactive protein, ferritin, carotenoids, vitamins, essential elements, the Norwegian Mother, Father and Child Cohort Study

Introduction

Poor nutritional status in pregnancy is associated with adverse health outcomes in the mother and child (1). In recent years, attention has been drawn to the consumption of ultra-processed foods (UPF). UPF can be defined as industrial formulations of foods whose major ingredients have undergone a series of physical, chemical, and biological processes (2). A high intake of UPF can result in poor nutritional status and excessive intake of salt, fats, and sugars, in addition to modified food substances, additives, and unwanted by-products or contaminants from extensive processing methods. UPF intake has been associated with obesity and development of non-communicable diseases, such as hypertension, diabetes, and dyslipidemia (3–7). However, whether UPF may affect health outcomes beyond its reduced nutritional value is not clear. While studies have shown how UPF intake relates to overall diet quality (8, 9), also in pregnancy (10, 11), data are scarce on the associations with biomarkers. Several *a priori* defined dietary indices have been developed to assess overall diet quality, also in pregnancy (12, 13). For assessment of intake according to the degree of food processing, the NOVA (not an acronym) classification is usually applied. Using NOVA, one classifies food groups according to the nature, extent, and purpose of industrial processing (2). The NOVA classification system is often used for studying associations between UPF intake and health outcomes (5), but usually not evaluated against nutritional biomarkers. Biomarkers in blood and urine are considered objective measures of nutrient status and widely used as a reference method in validation of dietary assessment methods (14). Few studies have, however, used biomarkers for evaluation of dietary quality indices.

This study aimed to (1) describe the concentrations and correlations of 22 nutrition and inflammation biomarkers measured in maternal blood sampled in pregnancy; and (2) explore associations between UPF consumption, a diet quality index (DQI) developed to assess adherence to Norwegian dietary guidelines, and concentrations of biomarkers of nutrition and inflammation status measured in pregnancy.

Materials and methods

Study participants

Our study is based on the first part of the Norwegian Environmental Biobank (NEB) project, which is a sub-study of the Norwegian Mother, Father, and Child Cohort Study (MoBa). MoBa is a population-based pregnancy cohort study conducted by the Norwegian Institute of Public Health (NIPH). Participants were recruited from all over Norway from 1999 to 2008 (15). The women agreed to participation in 41% of the pregnancies. Biological samples were obtained from mothers, fathers, and children (16). The cohort currently includes 114,500 children, 95,200 mothers, and 75,200 fathers. MoBa uses data from the medical birth registry (MBRN), which is a national health registry containing information about all births in Norway. The current cross-sectional study is based on version 12 of the quality-assured data files released for research in 2019.

In a subsample of MoBa, a range of biomarkers have been analyzed in blood and urine samples with the purpose of biomonitoring nutrients and environmental contaminants for pregnant women (17) (part one of the NEB). Selection of pregnant women in MoBa into NEB was based on availability of biological samples from mid-pregnancy and at birth. Only women with live-born singletons, and who had answered all questionnaires up until 3 years after giving birth were eligible. The study sample is restricted to participants recruited from 2002 to 2008 because the MoBa food frequency questionnaire (FFQ) was included in the data collection from March 2002. Also, women with children with autism or suspected autism were excluded. A total of 2,999 pregnant women were included in NEB. For this study, we excluded n = 15 subjects (5%), of which n = 13 had missing data and n = 2 had withdrawn. **Figure 1** outlines the flow of subjects for inclusion from the NEB sample.

Assessment of dietary intake and construction of food indices

In MoBa, a semi-quantitative and validated FFQ was used to assess maternal dietary habits and intake of foods, beverages, and dietary supplements during the first half of pregnancy (18, 19). Intake in grams per day for 255 foods and beverages, assuming standard portion sizes, and energy and nutrient intakes were calculated using FoodCalc (20) and the Norwegian food composition database (21).

Using the NOVA classification system for grouping foods according to the degree of industrial processing (2), we categorized foods and beverages from the MoBa FFQ into four groups (1 = minimally processed, 2 = culinary ingredients, 3 = processed foods, and 4 = UPFs), **Supplementary Table 1**. All food items from the FFQ were classified into one of the NOVA groups by two nutritionists with detailed knowledge about the MoBa FFQ and Norwegian diet (22). By combining the NOVA grouping with estimated intakes based on the FFQ, we calculated the energy contribution by each NOVA group to the total daily intake, resulting in four scores (scale 0–100%) for each participant. From this point and throughout the manuscript we are using the term "UPF intake" or "energy contribution of UPF on total intake" to describe the relative contribution of NOVA group 4 to total intake.

A pregnancy DQI was constructed specifically for use in MoBa based on the FFQ and the Norwegian food-based dietary guidelines. Borge et al. describes the detailed methods and formula used (23). The DQI is based on the healthy eating index (HEI), a well-known tool for measuring food consumption patterns and diet qualities to provide healthy nutritional recommendations for the USA population (13). The DQI includes 13 components, where each component has a maximum score of 10 (apart from total fish and fatty fish, which each has a maximum score of 5), for a total score of 110. The DQI score (scale 0–110) reflects the adherence to the Norwegian dietary guidelines and higher score units indicate better diet quality.

Assessment of biomarkers

The list of biomarkers measured in this study include CRP and ferritin measured in plasma, as well as nutrition biomarkers, including essential elements measured in whole blood (Cu, Mn, Mo, Se, Zn, in μg/L); vitamins including retinol (vitamin A, in mg/L), carotenoids (α-carotene, β-carotene, γ-carotene, α-cryptoxanthin, β-cryptoxanthin, lutein, lycopene, in mg/L), 25-hydroxy-vitamin-D (25-OH-D, in nmol/L), and tocopherols (α- and γ-tocopherol, in mg/L), measured in plasma; and Na, K and creatinine measured in urine (mmol/L).

During routine ultrasound visits around gestational week 18, MoBa women donated blood and urine samples (16). The biospecimen used in this study was collected from women who were in gestational week 18.5 (mean value, SD 1.3). Biochemical analyses of the nutritional and health related biomarkers were performed at the Department of Government Services (Biomarkers team), Finnish Institute for Health and Welfare (THL) in Helsinki, Finland. The laboratory (No. T077) has been accredited by the Finnish Accreditation Service (FINAS) and it fulfills the requirement of the standard SFS-EN ISO/IEC 17025:2017. Plasma CRP, ferritin, and vitamin D, as well as urinary K and Na, were measured using the Architect 8200ci integrated analyzer and assays developed for the purpose (Abbott Laboratories, Abbott Park, IL, USA). CRP (accredited method) was measured by the Multigent CRP Vario (CRPVa) assay, which is suitable for measuring CRP at variable assay ranges, including the low range requiring high sensitivity. P-Fe was analyzed by a chemiluminescent microparticle immune-assay (CMIA, ARCHITECT Ferritin assay, Abbott Laboratories). The Architect 25-(OH)-D assay (accredited method) was used for the determination of plasma vitamin D. The method is a high through-put automated chemiluminescent microparticle immunoassay, measuring both 25-(OH)-D2 and 25-(OH)-D3. Urinary K and Na were determined by Integrated Chip Technology (ICT) with ion-selective electrodes utilizing membranes selective to the ions (Abbott Laboratories). The laboratory participated in external quality assessment schemes organized by Labquality (Finland) and DEQAS (UK) for the above analytes.

Fat-soluble vitamins including retinol (vitamin A), carotenoids, and tocopherols (vitamin E) were also analyzed at the THL in Helsinki (Finland). High-performance liquid chromatography (HPLC) using an Agilent HPLC 1260 system

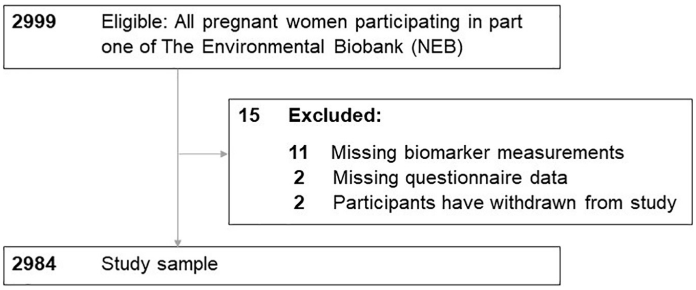

FIGURE 1
Inclusion of participants in the study sample. The Norwegian Environmental Biobank is a sub-study of the Norwegian Mother, Father, and Child Cohort Study (MoBa), including women who were pregnant in 2002–2008.

with a diode array detector (Agilent Technologies Inc., Santa Clara, CA, USA) was utilized. Plasma samples were protected from light during extraction and chromatographic analysis. Extraction was performed by using ethanol, potassium chloride, ascorbic acid, hexane, and butylated hydroxytoluene. Carotenoids were detected at 450 nm, except β-lycopene which was detected at 472 nm. Tocopherols were detected at 292 nm and retinol at 326 nm. Peak height/internal standard ratios were compared to those of reference plasma, the values of which were traceable to NIST certified serum standards, 968e (National Institute of Standardization and Technology, Gaithersburg, MD, USA). Echinenone, tocol, and retinyl acetate were used as an internal standard. The element analysis in whole blood were performed at Department of Occupational and Environmental Medicine at Lund University, Sweden (17). All determinations (Co, Cu, Mn, Mo, Se, Zn) were performed with inductive coupled plasma mass spectrometry (ICP-MS; iCAP Q, Thermo Fisher Scientific, Bremen, GmbH) equipped with collision cell with kinetic energy discrimination and helium as collision gas.

Other variables

The Medical Birth Registry of Norway and MoBa questionnaires provided lifestyle and sociodemographic factors. The following baseline characteristics were included: the women's age at delivery (years), parity (primiparous/multiparous), pre-pregnancy body mass index (BMI) (kg/m^2), completed educational level (low: $\leq$ 12 years, medium: 13–16 years; high: $\geq$ 17 years), maternal alcohol consumption during early pregnancy (yes/no), and smoking prior to or during pregnancy (no/sometimes/daily).

Ethics

The establishment and data collection in MoBa was previously based on a license from the Norwegian Data Protection Authority and approval from the Regional Committee for Medical Research Ethics, and it is now based on regulations according to the Norwegian Health Registry Act. The current study was approved by the Regional Committee for Medical Research Ethics (ref. 2014/314).

Statistical analysis

Associations between diet scores and nutritional biomarkers were explored using multiple linear regression models. We present the relative (%) increase in median biomarker concentrations and corresponding *p*-value of the associations in a volcano plot, which enables comparisons of the direction and magnitude of associations between all biomarkers and the two dietary indices. The outcome variables (biomarkers) were ln-transformed to approach normality. The relative (percent) change in concentrations of the biomarkers associated with a unit (c) change in the diet score was calculated by $(\exp(c^*\beta)-1)^*100\%$ and corresponding confidence intervals by $(\exp(c^*\beta \pm z1-\alpha/2^*SE(\beta))-1)^*100\%$ with $\alpha = 0.05$ and estimated βs and standard errors (SE) from the multiple regression analysis. We defined the unit c as the interquartile range (IQR, between first and third quartiles) to consider the observed range of the diet scores. The following covariates were considered as potential confounders and included as covariates: Age at delivery, pre-pregnancy BMI, education level, parity, alcohol consumption, and smoking during pregnancy. The variables with the largest proportion of missing data were pre-pregnancy BMI (3.6%) and early pregnancy alcohol consumption (10.8%). All adjusted analyses were performed based on complete case analysis. The linearity of associations between diet scores and nutritional biomarkers were inspected using non-parametric generalized additive models, using a restricted cubic spline with five knots as smoother. Bivariate correlations between dietary indices and biomarkers were investigated by Spearman's rank correlation coefficient. As an additional analysis, we investigated associations between inflammatory markers CRP and ferritin and all NOVA groups

1–4 (minimally processed to ultra-processed), as well as the DQI, using logistic and linear regression models. Statistical analyses were performed in R, version 4.1.0.

Results

The mean (SD) age of the study participants was 30 (4.2) years, and 51% were pregnant with their first child (Table 1). Most of the women had attained 13–16 years of education (45%), had a pre-pregnancy BMI between 18.5–24.9 kg/m^2 (63%), had no reported alcohol consumption in early pregnancy (87%), and were non-smokers (92%). Mean energy contributions for each NOVA group were 29% from foods in group 1 (minimally processed), 3% from group 2 (culinary ingredients), 22% from group 3 (processed), and 46% from group 4 (ultra-processed). Mid-pregnancy concentrations of biomarkers in plasma, urine and whole blood are shown in Table 2.

Ultra-processed food intake was negatively, but weakly correlated with the DQI (rho = −0.3, Supplementary Figure 1). While negatively correlated on a group level, the individual correlation varied; 2.2% of the women were in the first quartile (Q1) for both UPF and DQI, and 1.2% were in Q4 for both scores. In comparison, 28% were in completely opposite quartiles (Q1 and Q4) for the two indices, with 14% in each direction, respectively. Across quartiles of the DQI (Q1–Q4), the median values of UPF intake were 57% (Q1), 50% (Q2), 44% (Q3), and 35% (Q4). Biomarker concentrations were also correlated (Supplementary Figure 1).

To examine how biomarker concentrations were associated with UPF intake, we plotted the magnitude and significance of linear associations for the relative intake of UPF together with associations with the DQI in a volcano plot (Figure 2). An IQR increase (from the 25th to the 75th percentile) of energy contribution from UPF was positively associated with vitamin E (γ-tocopherol), creatinine, K, and Na (β: 5.6 to 16.5%; CI lower: 1.2 to 11.1%; CI upper: 10.1 to 22.2%), and negatively associated with all carotenoids (α-carotene, β-carotene, γ-carotene, α-cryptoxanthin, β-cryptoxanthin, lutein, lutein, lycopene), vitamin A, Mo, and Se (β: −2.1 to −17.9%; CI lower: −3.2 to −20.9%; CI upper: −1.0 to −14.6%). The DQI was positively associated with all carotenoids (α-carotene, β-carotene, γ-carotene, α-cryptoxanthin, β-cryptoxanthin, lutein, lycopene), vitamins (vitamin A and D), and Se (β:1.5 to 24.5%; CI lower: 0.05 to 20%; CI upper: 2.1 to 28.8%), and negatively associated with vitamin E (γ-tocopherol), creatinine, and Na (β: −4.8 to −8.3%; CI lower: −6.9 to −12.1%; CI upper:−2.6 to −4.3%). All unadjusted and adjusted effect estimates, and corresponding *p*-values are shown in Supplementary Table 2. Non-parametric generalized additive models showed clear linear relationships between UPF intake and concentrations of carotenoids, vitamin A (Figure 3), creatinine and Na (Figure 4).

Additional analysis showed weak, but positive associations between high UPF intake and inflammation biomarkers CRP and ferritin (Supplementary Tables 3–5). For instance, an IQR increase in UPF intake was associated with a 5.4% (CI lower: 0.12%, CI upper: 11%) increase in CRP concentration. No linear association was found between UPF intake and ferritin (Supplementary Table 3). However, the odds of high ferritin concentration (> 70 vs. 15–69 μg/L) was increased (odds ratio 1.4, CI lower: 1.1, CI upper: 1.9) when comparing the upper vs. lower quartile of UPF intake (Supplementary Tables 4, 5).

Discussion

In this cross-sectional study based on a large cohort of Norwegian women, we estimated associations between

TABLE 1 Study sample characteristics (*n* = 2,984).

	Study sample, (*n* = 2,984)
Age (years), mean (SD)	30 (4.2)
Parity, *n* (%)	
Nulliparous	1,529 (51)
Multiparous	1,455 (49)
Education, *n* (%)	
≤ 12 years	737 (25)
13–16 years	1,345 (45)
≥ 17 years	717 (24)
Missing	63 (2)
Pre-pregnancy BMI, *n* (%)	
< 18.5 kg/m^2	82 (3)
18.5–24.9 kg/m^2	1,897 (63)
25.0–29.9 kg/m^2	719 (24)
≥ 30.0 kg/m^2	231 (8)
Missing	55 (2)
Alcohol in pregnancy, *n* (%)	
No	2,594 (87)
Yes	67 (2)
Missing	323 (11)
Smoking during pregnancy, *n* (%)	
No	2,741 (92)
Occasionally	68 (2)
Daily	114 (4)
Missing	61 (2)
NOVA classification, relative (%) energy contribution to overall intake,[1] mean (SD)	
Minimally processed foods (group 1)	29 (8.7)
Processed culinary ingredients (group 2)	3 (3.3)
Processed foods (group 3)	22 (10.7)
Ultra-processed foods (group 4)	46 (14.1)
Diet quality index (DQI), mean (SD)[1,2]	83 (9.0)

Numbers are mean (SD) or *n* (%).
[1]NOVA classification and DQI was defined for *n* = 2,797 subjects with available FFQ data.
[2]Possible scoring range was 0–110, observed range was 46–104. Higher score indicates better quality.

biomarker concentrations and (1) UPF intake (according to the NOVA classification), and (2) scores from a DQI assessing adherence to Norwegian dietary guidelines. Our findings indicated that high consumption of UPFs was positively associated with urinary Na concentration, reflecting high intake of salt, and negatively associated with nutritional biomarkers, including carotenoids, vitamin A, selenium, and molybdenum, reflecting lower intake of vegetables, wholegrain and other foods that are recommended in a healthy diet. The associations between UPF consumption and the DQI with measured biomarkers showed inverse patterns, suggesting that the two dietary scoring systems capture high and low diet quality in a mirrored manner in this population. These findings are in line with those in a recent study where UPF intake was associated with lower diet quality assessed by HEI during pregnancy and postpartum in a USA study sample (10).

While concentrations of most vitamins were positively associated with DQI and negatively associated with the relative contribution from UPF, the opposite association was seen for γ-tocopherol. A likely explanation is that tocopherols are commonly used as antioxidants to inhibit peroxidation of fats and lipids in foods and thus is associated with the intake of UPFs (24). Notably, the biomarker concentrations reported in this study were measured in different matrices (whole blood, plasma, urine). The concentrations reported should be interpreted in light of the many physiological changes during pregnancy, such as hemodilution (25).

Our findings indicated weak, but positive associations between high intake of UPF and plasma CRP and ferritin concentrations, which are both markers of inflammation (26, 27). Increased inflammation is associated with pregnancy complications, and may therefore be of concern (28, 29). CRP has been shown to increase during pregnancy, but the patterns of change are inconsistent (30), and the specific effect of diet quality or dietary components on inflammation remains unclear. However, a recent systematic review described significant associations between dietary patterns and inflammatory markers during pregnancy (31). While diets rich in fruits, vegetables and whole-grain have been found to decrease CRP levels, meat-based western diets were associated with increased CRP levels in non-pregnant adults (32, 33). A suggested mechanism for the latter association is that UPF

TABLE 2 Summary statistics of biomarker concentrations measured in mid-pregnancy blood and urine samples (n = 2,984).

	Unit	Matrix	*n*	Mean	*SD*	Min.	P25	Median	P75	Max.
Carotenoids										
α-Carotene	mg/L	Plasma	2,984	0.07	0.05	0.004	0.038	0.06	0.09	0.46
β-Carotene	mg/L	Plasma	2,984	0.29	0.15	0.030	0.185	0.256	0.36	1.7
γ-Carotene	mg/L	Plasma	2,984	0.05	0.01	0.01	0.03	0.045	0.054	0.12
α-Cryptoxanthin	mg/L	Plasma	2,984	0.03	0.01	0.009	0.02	0.03	0.04	0.08
β-Cryptoxanthin	mg/L	Plasma	2,984	0.12	0.07	0.02	0.07	0.010	0.15	0.79
Lycopene	mg/L	Plasma	2,984	0.4	0.15	0.03	0.3	0.4	0.5	1.1
Lutein	mg/L	Plasma	2,984	0.19	0.06	0.05	0.15	0.18	0.22	0.46
Tocopherols (vitamin E)										
α-Tocopherol	mg/L	Plasma	2,984	13	2.5	5.7	11	13	15	31
γ-Tocopherol	mg/L	Plasma	2,984	0.91	0.39	0.17	0.63	0.83	1.1	3.02
Vitamin D (25-OH-D)[1]	nmol/L	Plasma	2,981	51	19	13	38	50	63	182
Vitamin A (retinol)	mg/L	Plasma	2,984	0.44	0.08	0.16	0.38	0.43	0.48	0.81
Creatinine	mmol/L	Urine	2,984	7.6	5.1	0.50	3.5	6.7	10	35
Elements										
K	mmol/L	Urine	2,984	50	30	4.0	27	45	69	204
Na	mmol/L	Urine	2,975	142	57	21	96	137	182	352
Co[2]	µg/L	Whole Blood	2,968	0.19	0.19	0.03	0.09	0.15	0.23	3.09
Cu[2]	µg/L	Whole Blood	2,968	1,554	250	610	1,388	1,542	1,702	3,633
Mn[2]	µg/L	Whole Blood	2,968	10	03.8	2.4	8.2	10	12	53
Mo[2]	µg/L	Whole Blood	2,968	0.73	0.44	0.14	0.49	0.63	0.82	7.2
Se[2]	µg/L	Whole Blood	2,968	105	23	42	89	102	117	353
Zn[2]	µg/L	Whole Blood	2,968	4,824	933	1,153	4,240	4,805	5,366	11,057
Inflammation markers										
C-Reactive protein (CRP)	mg/L	Plasma	2,982	6.4	7.7	0.11	2.6	4.6	7.6	189
Ferritin (Fe)[2]	µg/L	Plasma	2,984	43	34	3.2	20	33	55	304

[1]25-hydroxyvitamin D.
[2]Summary statistics for element concentrations in this study sample are previously published in Caspersen et al. (17).

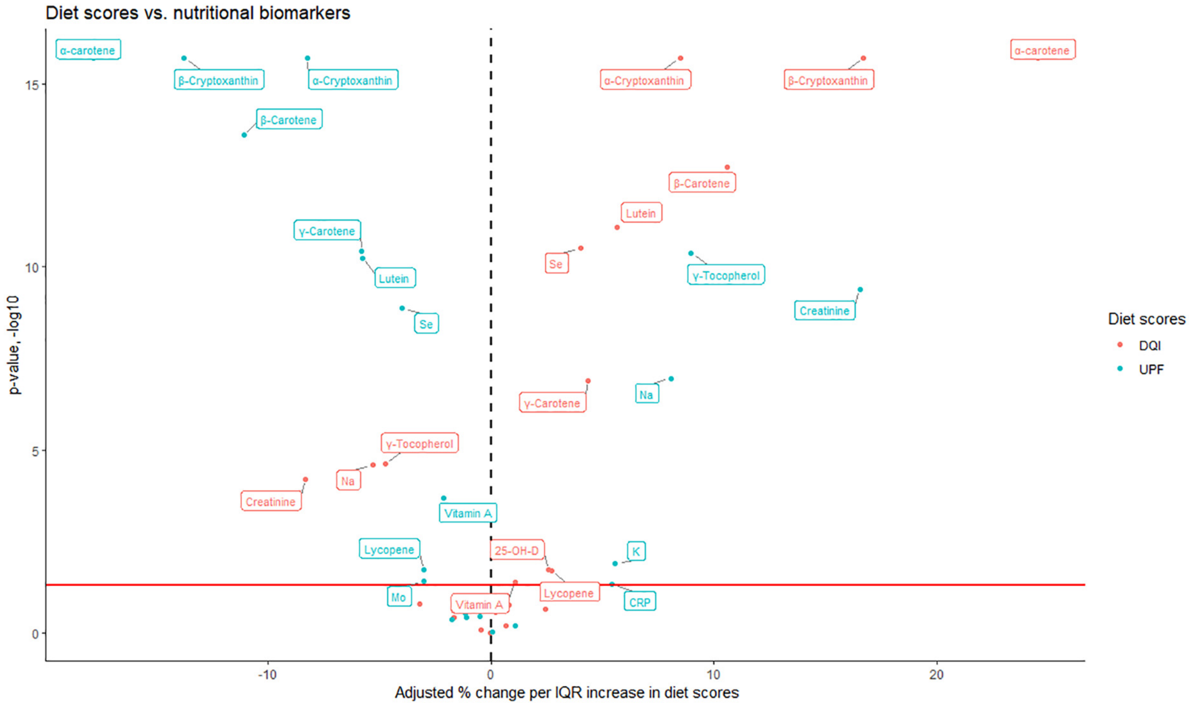

FIGURE 2
Adjusted relative (%) change in biomarker concentration according to an interquartile range (IQR, 25th–75th percentile) increase in diet scores (DQI and UPF), estimated by linear regression. Red horizontal line is indicating the −log10 transformed value corresponding to p-value = 0.05, and an increasing value on the y-axis corresponds to a decrease in the p-value. Only biomarkers with p-value < 0.05 are indicated with a text box. Adjusted for age at delivery, parity, pre-pregnancy BMI, education level, alcohol intake, and smoking status. CRP, C-reactive protein; DQI, diet quality index; UPF, ultra-processed food; 25-OH-D, 25-hydroxyvitamin D.

consumption could affect inflammatory status through changes in the gut microbiota (34). Moreover, a high degree of UPFs in the diet often leads to excess caloric intake and weight gain in comparison to an unprocessed diet (35), thereby indirectly increasing inflammation. These potential intermediate factors were not explored in this study.

The main strength of our study is the use of a validated FFQ and availability of a wide range of nutrition and inflammation biomarkers in a large sample of pregnant women. Additionally, access to extensive information about the participating women from the MoBa questionnaires allowed us to investigate associations between dietary indices and biomarkers while adjusting for a range of possible confounders.

There are some limitations to our study. MoBa participants are more often supplement users, non-smokers, primiparous, and have higher education compared to the general Norwegian pregnant population (36). Still, when comparing diet quality and biomarkers of nutrients within the same individuals, we expect that self-selection into the cohort is less problematic than in studies of exposure-disease outcomes. One can speculate that reported associations with dietary indices and biomarker status found in this sample could be of even greater magnitude in a more heterogeneous population (in terms of variation in exposure and biomarker concentrations) than studied here. Although we were able to adjust for a range of potential confounders, there is always a possibility that our results may be biased by unmeasured confounders, such as lifestyle, genetics and other physiological or dietary factors. We did not examine supplement use in this study. Associations between the two dietary indices and biomarkers may differ between users and non-users of supplements, and between users of supplements with different content. A previous study based on the same study sample showed that use of multimineral supplements was associated with increased concentrations of Mo and Se (17). However, if supplement use correlates to the DQI and UPF intake in a similar manner, we would still expect that the DQI and UPF intake are associated with biomarker concentrations in opposite directions.

We defined UPF consumption by applying the NOVA framework to consumption data of food groups assessed using an FFQ which was not designed for this specific purpose. This may limit the comparability with other studies. Also, this study is based on data collected during 2002–2008, and the content of the foods classified as UPF in this study may not be directly comparable to foods consumed now. The MoBa FFQ did not include sufficient detail for exact categorization into NOVA groups. Some groups may

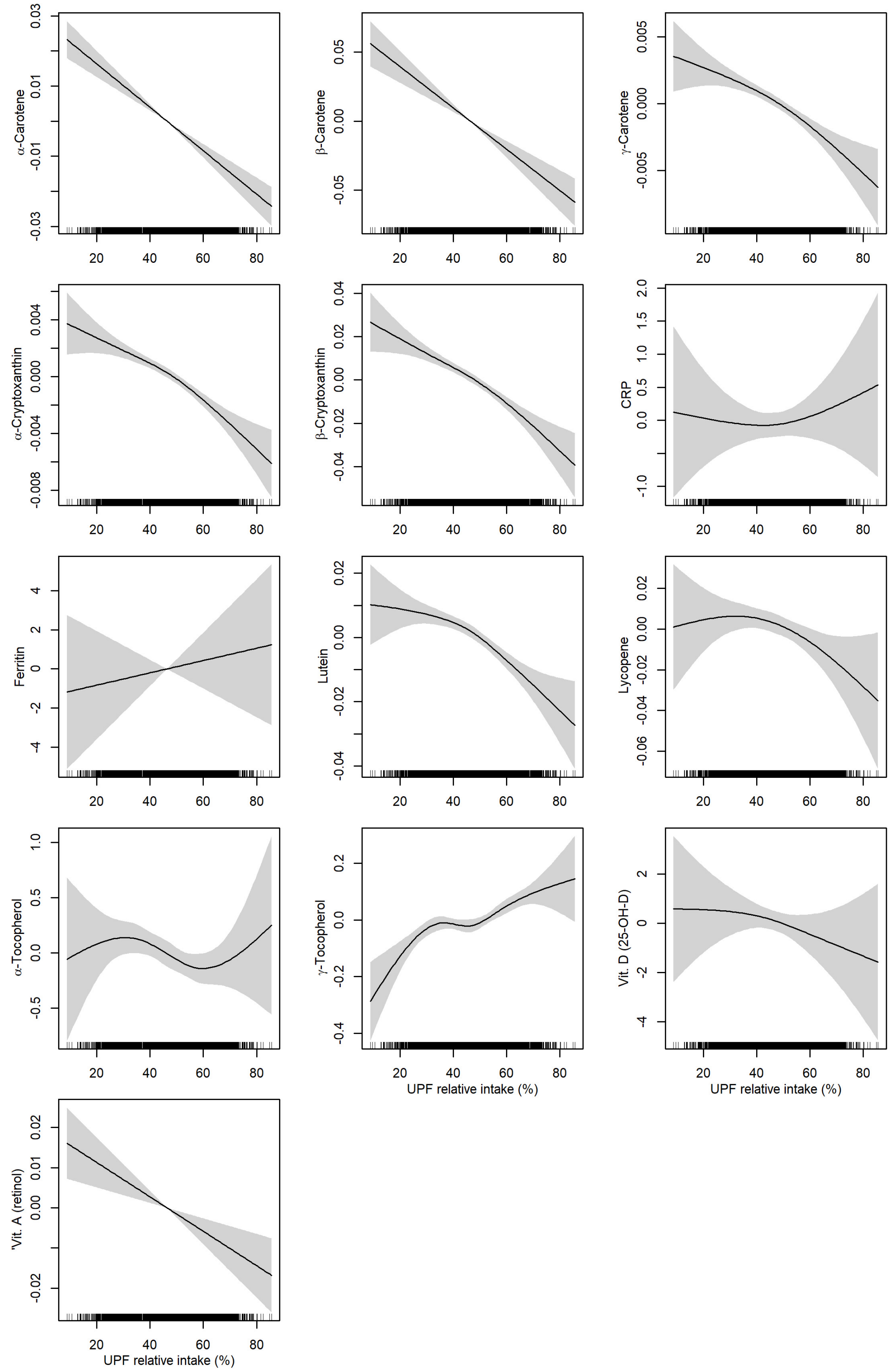

FIGURE 3
Adjusted associations between relative intake of ultra-processed food (UPF) and biomarkers measured in plasma. Associations were estimated by non-parametric generalized additive models using a restricted cubic spline with five knots as smoother. Adjusted for age at delivery, parity, pre-pregnancy BMI, education level, alcohol intake, and smoking status. CRP, C-reactive protein.

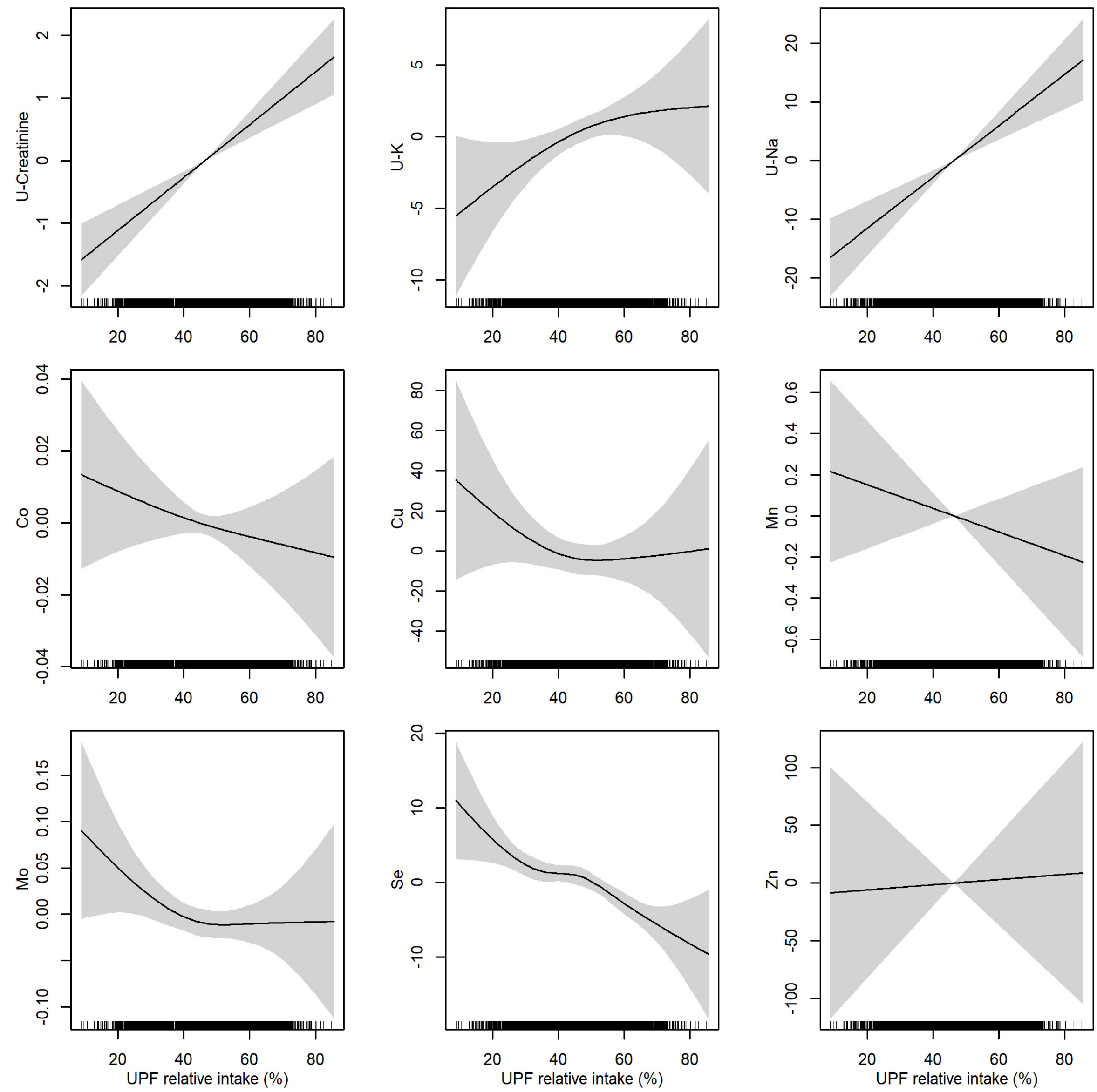

FIGURE 4
Adjusted associations between relative intake of ultra-processed food (UPF) and biomarkers measured in urine (indicated by "U-") and whole blood. Associations were estimated by non-parametric generalized additive models using a restricted cubic spline with five knots as smoother. Adjusted for age at delivery, parity, pre-pregnancy BMI, education level, alcohol intake, and smoking status.

be incorrect as they include items that may or may not include added sugar, and products that may or may not be homemade and in that case less processed. Although the interpretability of the NOVA classification system is discussed (37, 38), it is extensively used as a processing-based classification system in studies of diet quality and health outcomes, which facilitates comparisons between studies. Another limitation is that we have not described the intake of nutrients by UPF intake. However, the contrast and exclusive categorization of women by the DQI and UPF is still supporting that high UPF is related to poor nutritional status. Also the DQI was developed relying on the investigator's choice on how to create the index, specifically with regards to the number and weighting of components while calculating the DQI score (23). It has been argued that the accuracy of dietary indices depending on *a priori* approach can be limited by lack of dietary knowledge in terms of diet-health relationship and uncertain methodologies during index construction (39). However, the FFQ used in this study was specifically developed to assess habitual diet in the target population and provides reasonably valid dietary intake estimates (18). Additionally, utilizing composite measures of overall diet quality is considered less prone to misreporting compared to estimations of single nutrient intake (18, 39).

In conclusion, we found that a high relative contribution of UPF to total energy intake coincided with reduced concentrations of nutrition biomarkers in pregnancy. Inverse associations were found for high adherence to the Norwegian food-based dietary guidelines. The opposite directions of the associations with biomarkers seen for UPF intake and the DQI suggest that the two dietary scoring systems capture high and low diet quality in a mirrored manner in this population. Our findings shed light on the effect of UPF intake on nutritional status, using nutritional biomarkers, which should be considered when studying associations between consumption of UPFs in pregnancy and maternal and child health outcomes.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by the Regional Committee for Medical Research Ethics (ref. 2014/314). The patients/participants provided their written informed consent to participate in this study.

Author contributions

PTK, EP, TCB, ALB, and IHC prepared the data. PTK, EP, and IHC performed the statistical analyses. PTK and IHC wrote the first draft of the manuscript. EP, TCB, ALB, IE, HMM, LSH, CD, and IHC interpreted the results and revised the manuscript. IE was responsible for supervising the laboratory analyses. All authors read and approved the final version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1052001/full#supplementary-material

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Raquel Mendonça,
Universidade Federal de Ouro Preto,
Brazil

REVIEWED BY
Júlia Carraro,
Universidade Federal de Ouro Preto,
Brazil
Emyr Reisha Isaura,
Airlangga University, Indonesia

*CORRESPONDENCE
Catarina Machado Azeredo
catarina.azeredo@ufu.br

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Educational inequality in consumption of *in natura* or minimally processed foods and ultra-processed foods: The intersection between sex and race/skin color in Brazil

Barbara Virginia Caixeta Crepaldi[1], Letícia Martins Okada[1], Rafael Moreira Claro[2], Maria Laura da Costa Louzada[3], Leandro F. M. Rezende[4], Renata Bertazzi Levy[5] and Catarina Machado Azeredo[1]*

[1]Programa de Pós-Graduação em Ciências da Saúde, Faculdade de Medicina, Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, [2]Departamento de Nutrição, Escola de Enfermagem, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil, [3]Departamento de Nutrição da Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, SP, Brazil, [4]Departamento de Medicina Preventiva, Escola Paulista de Medicina, Universidade Federal de São Paulo, São Paulo, SP, Brazil, [5]Departamento de Medicina Preventiva, Faculdade de Medicina, Universidade de São Paulo, São Paulo, SP, Brazil

Background: It remains uncertain how the intersection between educational, gender, and race/skin color inequalities influences food consumption in Brazil. In this study, we examined the educational inequality in the consumption of *in natura*/minimally processed and ultra-processed foods by Brazilians with an intersectional perspective between sex and race/color.

Methods: We used cross-sectional data from the Telephone Surveillance System (VIGITEL 2019), comprising 52,443 participants $\geq$ 18 years. Daily food consumption was considered high when consumption of $\geq$5 foods for each food group was reported the day before the survey. Educational inequality in food consumption was assessed by the slope index of inequality (SII) and the relative index of inequality (RII) according to sex and race/color (White; Black/Brown). Positive SII and RII values $>$ 1.0 indicate higher food consumption among more educated participants.

Results: The consumptions of *in natura*/minimally processed and ultra-processed foods were more prevalent in those with the highest level of education ($\geq$12 years) and intermediate education (9–11 years), respectively. However, highly educated White women had higher consumption of *in natura*/minimally processed foods than Black women with the same education level, and White men in low and intermediate school levels had higher consumption of these foods than Black men with the same education levels. We found higher absolute educational inequality for *in natura*/minimally processed foods among White women (SII 21.8, 95% CI 15.3, 28.4) and Black/Brown men (SII 19.3, 95% CI 12.5, 26.1). Black/Brown men (SII 7.3, 95% CI 0.5, 14.0) and Black/Brown women (SII 5.6, 95% CI 1.0, 10.2) had higher absolute educational inequality than White men (SII −3.3, 95% CI −10.9, 4.3; $P = 0.04$) in the consumption of ultra-processed foods.

Conclusion: Educational inequalities influenced the consumption of *in natura*/minimally processed more than ultra-processed foods, and, for the latter, inequalities were greater among Black/Brown men and women than among White men.

KEYWORDS

food consumption, *NOVA*, social inequalities, ultra-processed food, intersectionality

Introduction

The participation of ultra-processed foods in diet has grown in the last few decades in different countries, especially in low- and middle-income countries (1, 2). In Brazil, for example, *in natura* or minimally processed foods have being intensely replaced by ultra-processed foods (3, 4). Ultra-processed foods are formulations of many ingredients, mainly of industrial use exclusively, which contain little or no intact food in their composition. These products are often added with a series of additives that provide attractive sensory attributes, such as texture, smell, and/or taste (5). The increasing consumption of ultra-processed foods is problematic because results in a general deterioration in the dietary nutritional profile and increases the risk of developing non-communicable diseases (NCDs) (6, 7).

The socioeconomic level, assessed mainly by income and educational attainment, is one of the major determinants of populational dietary patterns. In low- and middle-income countries, higher educational attainment, and income have been associated both with healthier dietary patterns (with higher consumption of fruits and vegetables and whole grains), but also with a higher intake of ultra-processed foods, such as sweets and candies, concomitantly, and paradoxically (8–11). In Brazil, despite the paradoxical pattern, the consumption of some ultra-processed foods, such as instant noodles and reconstituted meat products, is already more frequent among socially disadvantaged individuals (12).

Concomitantly, other sociodemographic characteristics, such as sex and/or skin color, also exert a great influence on populational dietary patterns (9). Brown men and women have lower regular consumption of fruits and vegetables compared to their White counterparts, and Black/Brown men have a higher regular consumption of beans when compared to White men (13). However, these comparisons between sex-skin color groups have not properly considered differences in socioeconomic level (13, 14). Socioeconomic inequalities observed in Brazil may interact and overlap with the race/color and sex dimensions (15). There is limited understanding of how the intersectional nature of sex and skin color/race determines the magnitude of socioeconomic inequalities in food consumption of individuals. The perspectives of intersectionality consider that the dimensions of inequality, such as race/color and sex, are interact and interdependent, and that these are experienced simultaneously (16, 17). Social inequalities in food consumption should be considered for NCDs prevention and control in low- and middle-income countries (10). Monitoring of food consumption and the interaction of equity stratifiers (education, sex, and race/color) can contribute to the development of equitable health policies.

In this study, we aimed to identify and quantify the magnitude of educational inequalities in the consumption of *in natura*/minimally processed and ultra-processed foods among Brazilians in 2019, according to the intersection between sex and race/skin color.

Methods

Study population, sampling, and data source

We used data from participants of the Brazilian Surveillance of Risk and Protective Factors for Chronic Diseases through Telephone Interviews (VIGITEL 2019), adults 18 years or older, residing in households with a landline in the 26 Brazilian state

Abbreviations: CAAE, Certificate of Presentation and Ethical Appreciation; CONEP, National Research Ethics Commission; IBGE, Brazilian Institute of Geography and Statistics; NCDs, non-communicable diseases; RII, relative inequality index; SII, slope of inequality index; UMIC, upper-middle-income country; VIGITEL, Surveillance of Risk and Protective Factors for Chronic Diseases through Telephone Interviews.

capitals and the Federal District. VIGITEL is a cross-sectional monitoring system for the frequency and distribution of the main determinants of NCDs, managed by the Brazilian Ministry of Health (18).

The sampling process consisted of drawing telephone lines by city, stratified by zip code, followed by drawing an individual residing in a selected household. The sample was weighted in order to minimize possible sampling biases, considering the non-universal coverage of the fixed telephone system and the difference in the probability of each individual being selected for the study. A final weight was assigned to each respondent, considering the inverse of the number of telephone lines in the respondent's household, the number of adults living in the household, and a third factor aiming to match the sociodemographic composition of the sample (sex, education, and age) in each city in 2019 to that of the entire population [based on official projection (Brazilian Institute of Geography and Statistics – IBGE] (Rake Method) (18). The final weight assigned to each interviewed participant (Rake Method), allows the correspondence of the population of individuals aged 18 years or more in each city, with and without fixed telephone line, in 2019 (18).

In the main analyses, we used data from the total sample (52,443 adults). The participants who did not know or did not want to inform their educational level (*n* 743; 1.4% of the initial sample) had their data imputed by VIGITEL, from the most frequently observed value considering sex and age (19). Information regarding self-declaration of race/skin color was audited for participants answering "others," in order to standardize the classification of synonyms, especially frequent in the case of Brown individuals (people who declared themselves, for example, *morenos*). At the end of the audit, the Black and Brown categories were grouped.

In the subgroup analysis by sex and race/skin color, participants who declared themselves Yellow (*n* 427; 0.8% of the initial sample) and Indigenous (*n* 617; 1.2% of the initial sample) were excluded due to the low frequency, which limits the power to detect significant differences within the group. In these analyses, participants who did not know or did not want to declare their race/skin color (*n* 1.163; 2.2% of the initial sample) were also excluded, totaling 50,236 included participants.

Study variables

Consumption of *in natura*/minimally processed and ultra-processed foods

Consumption of *in natura*/minimally processed (fruits, vegetables, roots and tubers, grains, legumes, meat, eggs, milk, nuts, and seeds) were evaluated in relation to the day before the interview, representing markers of healthy eating (18). In addition, consumption of ultra-processed foods (soft drinks, artificial juices, powdered drink mixes, powdered chocolate milk mix, flavored yogurt, salty snacks, sweet cookies and cake, sweet desserts, reconstituted meat products, bread, sauces, margarine, and ready-to-heat products) were evaluated in relation to the day before the interview, representing markers of unhealthy eating (18). The two food groups relied on the *NOVA* classification, which categorizes foods according to the extent and purpose of their processing (5). More details about the foods included in the *in natura*/minimally processed and ultra-processed food groups are provided in **Supplementary material 1**.

Food consumption was assessed through the following question: "Now I am going to list some foods and I would like you to tell me if you ate any of them yesterday (from when you woke up to when you went to sleep)." In order to assess the consumption of *in natura*/minimally processed and ultra-processed foods, respectively, the instruction was followed by questions in the following format: "I will start with *in natura* or staple foods [specific foods mentioned in the interview, described in **Supplementary material 1**] (yes or no)," and "Now I will list industrialized foods or products [specific foods mentioned in the interview, described in **Supplementary material 1**] (yes or no)" (18). The food questionnaire used by VIGITEL 2019 was based on instruments with satisfactory validity in Brazil, as documented by Sattamini (20).

A daily consumption equal to or higher than 5 different foods for each food group (*in natura*/minimally processed foods and ultra-processed foods) was considered as "high consumption," in compliance with the assessment parameter adopted by VIGITEL (18). In the Brazilian context, a consumption equal to or greater than 5 groups of ultra-processed foods reflects a participation of about 44.0% of ultra-processed foods in the total caloric value of the diet (21).

Equity stratifiers

Food consumption was described according to years of schooling (0–3; 4–8; 9–11; ≥12 years) and the intersection between sex and race/skin color (White men; Black/Brown men; White women; Black/Brown women).

The categories of school level we used, are based on Brazilian cutoffs for illiterate/less than primary school (0–3 years of study), primary (elementary) school (4–8 years), secondary (middle) school (9–11 years) and higher education (≥12 years of study). In Brazil there is a marked difference between job types and income level based on these categories of education, thus we used these categories to capture not only the role of education, *per se*, but also indirectly the role of income. In addition to the use of complex measures of inequality that consider all levels of education, we aimed to verify the frequency of consumption of *in natura*/minimally processed foods and ultra-processed foods according to years of education. Considering that the different levels of education may present differences in food consumption, the use of ordered stratifiers with more than two categories is more informative.

Statistical analysis

The sociodemographic characteristics and food consumption were expressed in means or relative frequencies for the total sample and subgroups with intersection between sex and race/color. For the presentation of inequalities in food consumption according to schooling in the total sample and subgroups, graphs of equiplot type were generated (Pelotas, Brazil).[1]

We calculated simple measures of inequality (22), such as absolute difference [most educated group (≥12 years of study) – least educated group (0–3 years of study)] and ratio (most educated group/least educated group) of the prevalence of consumption *in natura*/minimally processed and ultra-processed foods in the total sample and subgroups with intersection between sex and race/color.

Complex measures of inequality

The magnitude of inequality in food consumption was estimated based on the level of education (educational inequality) through absolute (slope index of inequality – SII) and relative differences (relative index of inequality – RII) (22).

The SII represents the difference in the prevalence of food consumption between the more educated and less educated groups (difference in prevalence), whereas the RII represents the ratio of the prevalence between these groups. SII and RII consider all levels of schooling in the population instead of just comparing the two most extreme groups of schooling (23). SII and RII were estimated based on education for the total sample of participants and the subgroups with the intersection between sex and race/skin color.

Slope index of inequality and RII were estimated through logistic regression, a more appropriate analysis in the presence of prevalence indicators (24). The obtained SII values were multiplied by 100, ranging from −100 to +100, to facilitate visualization and understanding of results. Negative SII values indicate that food consumption is more prevalent in less educated groups, while positive values indicate a higher prevalence in more educated groups. SII values equal to ± 100 express total inequality, whereas zero represents a situation of total equality (absence of inequality) (22).

In general, the RII measures assume positive values (23), in which values farther from than 1.0 reflect higher levels of inequality (25). Results higher than 1.0 indicate a concentration of food consumption among more educated individuals and values lower than 1.0, including negative values, indicate a gradient in favor of the less educated ones (23, 25). If there is no inequality, the RII assumes a value of 1.0 (25).

SII and RII values were estimated with 95% confidence intervals. We performed the *t*-test to analyze whether educational inequality in food consumption assessed by SII and RII differed between subgroups (considering all possible comparisons). Associations with a value of $P < 0.05$ were considered statistically significant.

Population attributable risk

In order to quantify inequality, we also calculated the population attributable risk, an absolute inequality measure that shows the possible improvement (in percentage points) in food consumption if all schooling categories had the same prevalence of food consumption as the most favored group (here considered ≥ 12 years of study) (22). The population attributable fraction, a relative inequality measure, represents the possible proportional improvement if there was no inequality between the categories of schooling. Higher results indicate more pronounced inequalities (22, 26).

Regarding population attributable risk, the prevalence of food consumption identified in the most favored group was subtracted from that in the total population (here considered for the total sample and the sample of each subgroup with intersection between sex and race/color). The population attributable fraction was obtained by dividing the absolute population attributable risk by the prevalence of food consumption in the total population (22).

Statistical analyses and graphs were performed using the Stata/SE software version 16 (StataCorp LLC, College Station, United States), considering the VIGITEL sample design for descriptive analyses (*Stata's survey* module) and the weights of the sample in the estimation of SII and RII values.

Results

In our study population, 54.0% correspond to women and 55.2% of the participants self-declared as Black/Brown race/color. The mean age among total sample was about 43 years old (SD 16.7) and the most frequent education category was between 9 and 11 years of study (38.4%). The sociodemographic distribution of participants according to the intersecting subgroups between sex and race/color and the percent of consumption of each food group is presented in **Table 1**. We identified a higher prevalence of participants with education between 9 and 11 years of study among Black/Brown men and women while the most frequent education category among White men and women was 12 or more years of study. In general, the percent of high consumption of *in natura*/minimally processed foods (≥5 different foods on the previous day) was low (29.8%), especially among Black/Brown men (25.2%), White men (29, 6%), and Black/Brown women

1 www.equidade.org/equiplot

TABLE 1 Sociodemographic characteristics, prevalence of consumption of *in natura*/minimally processed foods and ultra-processed foods in Brazil.[a]

General characteristics of the sample	Total sample		White men (38.7%)		Black/Brown men (55.8%)		White women (42.9%)		Black/Brown women (54.6%)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Age (years)										
Mean	42.7		42.3		39.1		46.0		42.8	
SD	16.7		17.1		15.3		17.6		16.1	
Years of education										
0–3 years	06.3	05.9, 06.7	04.8	04.0, 05.7	06.1	05.2, 07.2	05.4	04.7, 06.2	07.2	06.5, 08.1
4–8 years	22.5	21.7, 23.4	18.5	16.7, 20.6	24.1	22.2, 26.1	20.8	19.4, 22.4	23.0	21.7, 24.4
9–11 years	38.4	37.5, 39.3	33.4	31.1, 35.8	45.3	43.2, 47.3	31.1	29.5, 32.8	42.0	40.4, 43.5
≥12 years	32.8	31.9, 33.7	43.2	40.8, 45.8	24.5	22.9, 26.3	42.6	40.8, 44.4	27.8	26.4, 29.2
High consumption of[b]										
In natura/Minimally processed foods	29.8	28.9, 30.6	29.6	27.5, 31.8	25.2	23.5, 26.9	35.7	34.0, 37.4	29.7	28.3, 31.0
Ultra-processed foods	18.2	17.4, 19.0	20.0	18.0, 22.0	23.8	21.9, 25.7	14.8	13.3, 16.3	15.6	14.4, 16.9

VIGITEL, Surveillance of Risk and Protective Factors for Chronic Diseases through Telephone Interviews.
SD, standard deviation; CI, confidence interval.
[a]Sociodemographic characteristics, prevalence of consumption of each food group (*in natura*/minimally processed foods and ultra-processed foods), by intersection of sex and skin color/race, VIGITEL 2019.
[b]Consumption equal to or higher than 5 different foods from each food group, the day before the interview.

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(29.7%). The high consumption of ultra-processed foods (≥5 different foods on the previous day) was observed in almost a fifth of the total sample (18.2%), with a higher frequency among Black/Brown men (23.8%) and White men (20.0%) (Table 1).

The consumption of *in natura*/minimally processed foods by the total sample and subgroups was lower among less-educated participants than the more educated ones. Although White men had a lower educational discrepancy, we observed an important educational gradient among White women (Figure 1A). At the highest level of education (≥12 years of study), White and Black/Brown men had a similar consumption frequency (approximately 34.0%). However, the prevalence of consumption was higher in less educated White men compared to Black/Brown men with intermediate education. Among more educated women, White women had a higher consumption frequency than Black/Brown women, especially when considering the highest level of education (41.6% vs. 35.4%). However, at the highest level of education, Black/Brown women had a consumption frequency similar to that of men (Black/Brown and White) (Figure 1A). In general, among the *in natura*/minimally processed foods included in this study, vegetables and nuts and seeds were the food categories that most clearly showed a pattern of consumption inequality favoring more educated individuals (see Supplementary material 2).

Differently, for the consumption of ultra-processed foods, a higher prevalence was identified among participants with intermediate education (9–11 years of study) in the total sample and subgroups. We observed a higher educational discrepancy between White and Black/Brown men. White men with intermediate education, and especially those with the highest level of education (≥12 years of study), had a lower frequency of consumption of ultra-processed foods compared to their respective Black/Brown counterparts (17.3% vs. 23.1% in the highest level of education). A slight educational discrepancy was observed between White and Black/Brown women (Figure 1B). The ultra-processed foods that were more frequently consumed by Brazilians were margarine and bread, with higher prevalence among participants with intermediate education and those with

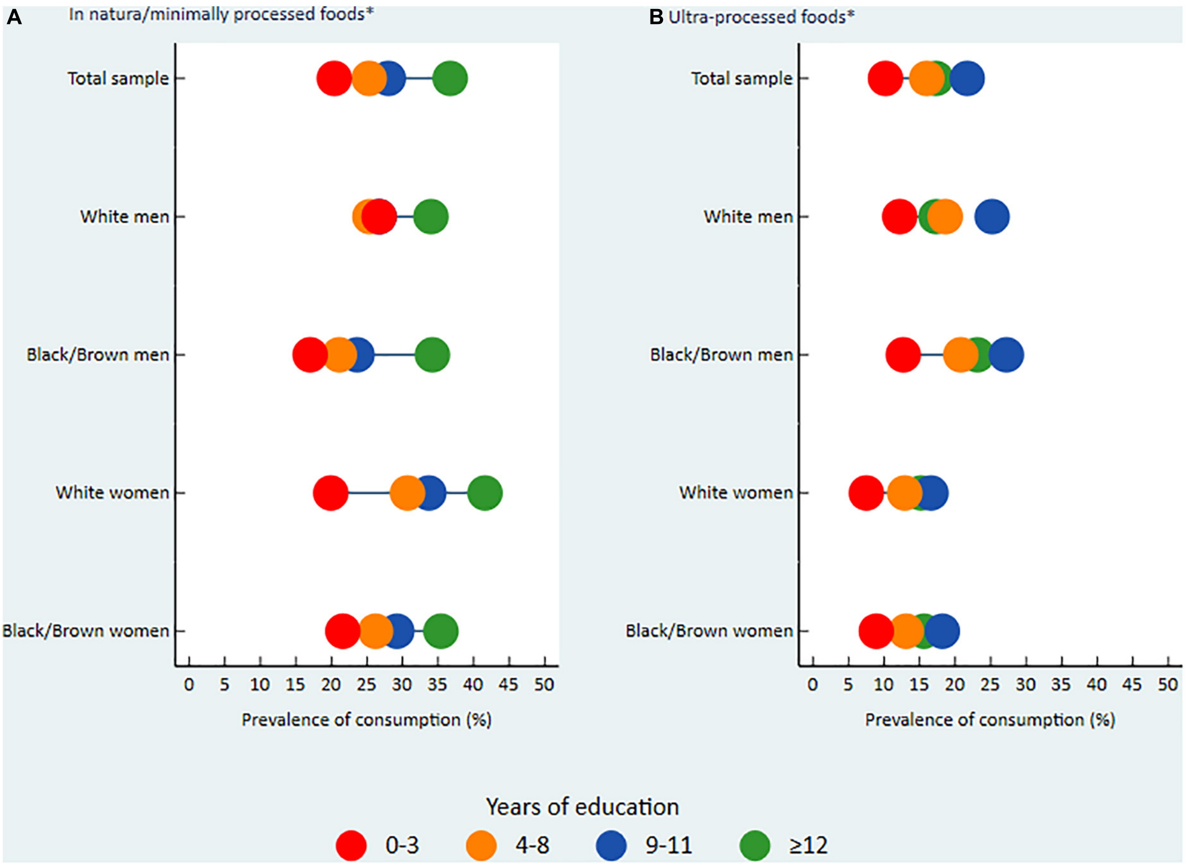

FIGURE 1
Prevalence of consumption of *in natura*/minimally processed foods **(A)** and ultra-processed foods **(B)** in Brazil.[a] VIGITEL, Surveillance of Risk and Protective Factors for Chronic Diseases through Telephone Interviews. [a]Prevalence of consumption of each food group [*in natura*/minimally processed foods **(A)** and ultra-processed foods **(B)**], by years of education and intersection of sex and skin color/race, VIGITEL 2019 (equiplot). *Consumption equal to or higher than 5 different foods from each food group, the day before the interview.

a higher level of education, respectively (see **Supplementary material 3**).

Among the most educated groups, the most frequent consumption of *in natura*/minimally processed foods and ultra-processed foods was also identified through positive SII results and RII results above 1.0 (**Table 2**). Educational inequality was higher for the consumption of *in natura*/minimally processed foods (SII 19.3, 95% CI 16.1, 22.5; RII 1.9, 95% CI 1.7, 2.1) than for ultra-processed foods (SII 3.6, 95% CI 0.7, 6.6; RII 1.2, 95% CI 1.0, 1.4), mainly identified by absolute measures. In general, the values found for the simple measures of inequality, difference, and ratio also confirmed that the consumption of these two food groups was more prevalent among more educated participants (**Table 2**).

The consumption of *in natura*/minimally processed foods remained concentrated among the most educated individuals in all intersectional subgroups of sex and race/skin color. The magnitude of absolute and relative inequalities was higher in Black/Brown men (SII 19.3, 95% CI 12.5, 26.1; RII 2.2, 95% CI 1.5, 2.8) and White women (SII 21.8, 95% CI 15.3, 28.4; RII 1.9, 95% CI 1.5, 2.2). The population attributable risk results indicate that, if educational inequality were eliminated, the consumption of *in natura*/minimally processed foods would increase by 9.0 percentage points and 35.7% for Black/Brown men and 5.7 percentage points and 19.2% among Black/Brown women (**Table 2**).

In the analysis of the magnitude of educational inequality in the consumption of ultra-processed foods, we identified a significant absolute inequality for Black/Brown men (SII 7.3, 95% CI 0.5, 14.0) and Black/Brown women (SII 5.6, 95% CI 1.0, 10.2), but not for White men and women. However, we observed among White men a possibly higher consumption of ultra-processed foods in the least educated individuals (SII −3.3, 95% CI −10.9, 4.3; RII 0.9, 95% CI 0.5, 1.2). In the comparison between subgroups, Black/Brown men and women showed a higher absolute inequality in relation to White men ($P = 0.04$, for both). If educational inequality ceased to exist among White men, there would be a reduction of 2.7 percentage points and 13.5% in the consumption of ultra-processed foods (**Table 2**).

Discussion

The present study showed that the consumption of *in natura*/minimally processed foods was more prevalent in participants with a higher level of education, while that of ultra-processed foods was more frequent among those with intermediate education in the total sample and all analyzed subgroups with the intersection between sex and race/skin color. In middle-income countries, such as Brazil, the level of education influences the employability and income of the population (27, 28). Higher educational level impacts on a higher socioeconomic level (29), and influences healthy food choices even in the lower income population (30). In addition, considering that the price of healthy foods, such as fruits and vegetables, tends to be higher than the price of ultra-processed foods in Brazil (31), such factors may justify the more frequent consumption of *in natura*/minimally processed foods among the most educated in the present study. On the other hand, the more frequent consumption of ultra-processed foods among people with intermediate education (9–11 years of study) is possibly due to the considerable participation of this group in the informal labor market, characterized by intense working (32) that can make it difficult to buy and prepare food/drinks at home (33).

The consumption of *in natura*/minimally processed foods was the food group that showed the highest absolute educational inequality, especially between White women and Black/Brown men, while White men showed lower absolute and relative inequality. Additionally, in the consumption of ultra-processed food, Black/Brown men and women had a significantly higher absolute inequality than White men. Elimination of educational inequality would result in increased consumption of *in natura*/minimally processed foods of 36.0% for Black/Brown men and 19.0% for Black/Brown women. In addition, the elimination of educational inequality among White men would reduce the consumption of ultra-processed food by 13.5% in this group.

We identified that Black/Brown men with low to intermediate levels of education consumed less *in natura*/minimally processed foods than White men with lower levels of education. Considering that a higher level of education implies better wages in Brazil (27) and that having higher incomes increases the opportunity for adherence to the consumption of healthy foods (34), it would be expected that the intermediate education level of Black/Brown men would favor higher access to and consumption of these foods in relation to less educated White men. However, in a country marked by a historical and expressive racial inequality in social indicators, Black/Brown men only had the same prevalence of healthy food consumption as White men in the highest level of education. This result may be explained by the fact that, although the unemployment rate is higher among Black/Brown people than among White people, regardless of education, this difference is relatively smaller among those with a higher level of education, although the wage disadvantages remain expressive (27).

We identified that Black/Brown women with the highest level of education achieved the prevalence of consumption of *in natura*/minimally processed foods of their respective counterparts of White men and Black/Brown men, despite Black/Brown women having the worst work income in Brazil (for example, 44.4% of White men's earnings) (35). Unequally, considering that education determined more the differences in the consumption of healthy foods among White women than among the other subgroups, we observed, in the highest level of education, an expressive lower frequency of consumption of

TABLE 2 Consumption of *in natura*/minimally processed and ultra-processed foods, as well measures of inequality in Brazil.[a]

Consumption of food groups[b]	**Simple measures of inequality**				**Complex measures of inequality**				**Population attributable risk (percentage points)**	**Population attributable fraction**
Subgroups of sex and skin color/Race	**% lowest education (0-3 years of study)**	**% highest education (≥ 12 years of study)**	**Absolute difference**	**Ratio**	**SII**	**95% CI**	**RII**	**95% CI**		
In natura/Minimally processed foods										
Total sample	20.4	36.7	16.3	1.8	19.3	16.1, 22.5	1.9	1.7, 2.1	−6.9	−23.2
White men	26.7	34.0	7.3	1.3	14.7	5.8, 23.6	1.6	1.2, 2.1	−4.4	−14.9
Black/Brown men	17.0	34.2	17.2	2.0	19.3	12.5, 26.1	2.2	1.5, 2.8	−9.0	−35.7
White women	19.9	41.6	21.7	2.1	21.8	15.3, 28.4	1.9	1.5, 2.2	−5.9	−16.5
Black/Brown women	21.6	35.4	13.8	1.6	15.1	10.1, 20.1	1.7	1.4, 1.9	−5.7	−19.2
Ultra-processed foods										
Total sample	10.2	17.3	7.1	1.7	3.6	0.7, 6.6	1.2	1.0, 1.4	0.9	4.9
White men	12.2	17.3	5.1	1.4	−3.3	−10.9, 4.3	0.9	0.5, 1.2	2.7	13.5
Black/Brown men	12.7	23.1	10.4	1.8	7.3	0.5, 14.0*	1.4	1.0, 1,7	0.7	2.9
White women	07.5	15.2	7.7	2.0	4.7	−1.1, 10.5	1.4	0.8, 1.9	−0.4	−2.7
Black/Brown women	08.9	15.6	6.7	1.8	5.6	1.0, 10.2**	1.4	1.0, 1.8	0.0	0.0

VIGITEL, Surveillance of Risk and Protective Factors for Chronic Diseases through Telephone Interviews.
SII, slope of inequality index; CI, confidence interval; RII, relative inequality index.
Difference = Highest education − Lowest education; Ratio = Highest education/Lowest education.
SII and RII values were significantly different according to *t*-test.
[a]Prevalence of consumption of each food group (*in natura*/minimally processed foods and ultra-processed foods), as well as simple and complex measures of inequality and absolute and relative population attributable risk by intersection of sex and skin color/race, VIGITEL 2019.
[b]Consumption equal to or higher than 5 different foods from each food group, the day before the interview.
*Difference between White men and Black/Brown men (*P*-value = 0.04).
**Difference between White men and Black/Brown women (*P*-value = 0.04).

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healthy foods among Black/Brown women in relation to White women. Brazilian women have better educational indicators compared to men, and White women have higher work incomes than Black/Brown women (35). The greater education of women associated with higher income among White women may have contributed to the higher consumption of healthy foods in this group (11, 28, 36). Healthy eating patterns among Brazilian women, especially those with higher education and income, have been identified in other epidemiological studies (8, 9, 37).

We also identified an important privilege of White skin among more educated men, favoring a lower frequency of consumption of ultra-processed foods in relation to their Black/Brown male counterparts. While higher levels of education seem to facilitate the consumption of ultra-processed products among Black/Brown men and women, educational inequality among White men showed that the consumption of ultra-processed food already seems to reach the less socioeconomically advantaged population in a more concentrated manner. The White men's wage advantages in relation to all subgroups (35) may have contributed to this finding.

The consumption of ultra-processed foods reaching White men with less education in a more concentrated manner and a slighter educational discrepancy in the subgroups for this food group reinforce the occurrence of the food transition process in Brazil (9), which has already occurred in developed countries (38, 39). The progression of the dietary pattern transition is characterized by higher consumption of cheaper, more caloric, and less nutritious foods at lower educational and income levels (1, 38, 39). In developing countries, such as Brazil, unhealthy food options are increasingly more accessible (40). On the other hand, healthy foods such as fruits and vegetables observed continuous increases in its price (40).

Projections of the price of healthy and unhealthy foods from 2017 to 2030 in Brazil, using data from 1995 to 2017, showed that the price difference between these foods reduced over time and forecasted that ultra-processed foods will become cheaper than *in natura*/minimally processed foods as of 2026 (41). This would increase barriers to the consumption of healthy foods (42) and encourage the consumption of unhealthy foods, specially by people with lower incomes, as a way to control expenditures (34), widening dietary and health inequalities. The growing participation of ultra-processed foods in the diet of the Brazilian population has been observed in recent decades (3), including in the most vulnerable populations (12). Data from the Brazilian Household Budget Surveys 2017-2018, show that ultra-processed foods already contribute about one-fifth (19.7%) of the calories consumed by Brazilians, and that the consumption of some ultra-processed foods, such as instant noodles and reconstituted meat products, is more frequent in the lowest income quartiles of the population (12). In addition to the economic factor, food consumption can be influenced by other issues such as cultural, ethnic, and perceived racial discrimination (14, 42).

Robust epidemiological evidence on negative health effects associated with the consumption of ultra-processed foods has been described (6). High consumption of ultra-processed foods has been associated with higher calorie intake, body fat gain (43), overweight/obesity risk (6), type-2 diabetes (44), breast cancer (45), cardiovascular diseases, depression, and mortality for all the causes (6). Specifically for obesity, a study in the North American population showed that, for all levels of education, the age-adjusted prevalence of overweight/obesity was 44.0% higher in Black women than in White women and 2.0% higher in Black men than in White men (46). Thus, the consumption of ultra-processed foods may increase overweight, especially in the Black population, with emphasis on women, accentuating health inequalities.

It is expected that the consumption of ultra-processed foods will become more frequent in more vulnerable populations within a few years, such as Black/Brown and less educated individuals, if intersectoral and effective interventions are not articulated and adopted quickly. The guidelines for promoting the consumption of healthy foods and discouraging the consumption of unhealthy foods must be accompanied by plausible cultural and economic strategies for population adherence, especially the less educated and poorer (34, 42), because the ongoing COVID-19 pandemic enhances social, racial, and gender inequalities that already exist in Brazil (47). Public policies aimed at subsidizing *in natura* or minimally processed foods (48), may be effective in increasing purchase and consumption power of these foods by the vulnerable population (48, 49). In addition, a favorable a food environment with a high density of healthy eating establishments, such as street markets, is needed (50).

In addition to subsidizing healthy foods, the taxation of ultra-processed foods may discourage their consumption, especially by the most vulnerable population (48, 49). In Brazil, the price of ultra-processed foods was inversely associated with the prevalence of overweight and obesity, especially protecting individuals with higher socioeconomic vulnerability (51). In the same way, food marketing regulation can also contribute to improving the quality of the population's diet (49). A new labeling system was recently approved in Brazil, encompassing frontal nutrition labeling and a magnifying glass design to identify high nutrient content, including added sugars (52). Despite this, the Brazilian model differs from those adopted by other Latin American countries and jurisdictions in the United States, with scientific evidence of beneficial effects (53). Complementary measures are needed to reduce the persuasive advertising of ultra-processed foods on television and the internet, identified in Latin American countries, including Brazil (54–56).

Our results show the importance of ensuring access to better educational opportunities, with emphasis on the

Black/Brown population, as a way to improve the quality of food consumption. It is noteworthy that, despite the growing participation of the Black/Brown population in higher education in recent years, due to the increase in the number of places and the policies of democratization of access to public higher education, the percentage of Black/Brown individuals with complete higher education is still low compared to White population (32.0% *vs.* 66.0% in 2017) (57, 58). In addition to the benefit of education in the employability and income of the population (27), knowledge, including specific to health (28), such as information on types and characteristics of foods that contribute to making them more or less healthy, may also influence an adequate diet (42).

Our study has some limitations. VIGITEL collected data from individuals with access to a landline residing in Brazilian state capitals and the Federal District. Although weighting factors have been used to mitigate this limitation, the inclusion of the population without a landline in the System (having only a cell phone) has the potential to impact the estimates, such as a higher frequency of consumption of some ultra-processed foods (59). There is a possibility that respondents have a higher socioeconomic level than the population of capitals in general, because, in Brazil, access to fixed telephone lines has been reduced in recent years (60), and more socioeconomically privileged families are more likely to have a landline (61). Nevertheless, we identified the presence of expressive educational inequalities with the intersection between sex and race/color in food consumption. We did not include participants who declared themselves either Yellow or Indigenous in the intersection analysis due to limited sample size. This study innovates and advances in the perspective of intersectionality, showing the overlapping of inequalities in food consumption in Brazil. Another limitation is that the self-reported information made available by VIGITEL is subject to misclassification. However, there is an indication of good reproducibility and adequate validity of indicators of food and beverage consumption obtained through telephone surveys (62). Although VIGITEL used a method based on a list of foods (simplified food questionnaire) and not the open 24-h dietary recall, the simplified version was based on instruments with satisfactory validity, and the lack of quantification of consumption did not impact the understanding of the quality of the diet in the healthy and unhealthy dimensions proposed by the instrument (20, 21).

The strengths of the study are the analysis of the magnitude of social inequality in the consumption of two food groups (*in natura*/minimally processed and ultra-processed foods) of the *NOVA* classification, which has become a world reference for effective assessment of the quality of diets and their consequences in all forms of malnutrition (1, 4, 5). We used complex measures of inequality that took into account all levels of education of the representative sample of the population of the state capitals and the Federal District of an upper-middle-income country (UMIC) (63). Furthermore, our study fills a gap in the literature on the role of the intersectionality of sex and race/skin color in food consumption.

The present study has important implications for public health as it identifies the magnitude with which social inequality presents itself and the groups that are the most vulnerable to the consumption of foods classified according to the degree of processing. Our results can subsidize policies that equitably guarantee the possibility of adopting the golden rule: "always prefer *in natura* or minimally processed foods and freshly made dishes and meals to ultra-processed foods" presented in the renowned Dietary Guidelines for the Brazilian Population, which has a language accessible to less educated people (42). A variety in the consumption of *in natura* and minimally processed foods and the reduction in the consumption of ultra-processed foods goes beyond the fundamental importance of promoting healthy eating for the population (20). It implies the promotion of an environmentally sustainable and socially fairer food system (42, 64), mitigating the deepening of social inequalities caused by the food system that produces ultra-processed products (42).

We conclude that the inequality in the consumption of *in natura*/minimally processed foods favors more educated individuals. The prevalence of consumption of ultra-processed foods is more concentrated among those with intermediate education. Educational inequalities influence more the consumption of healthy than unhealthy foods. Among the subgroups, Black/Brown men with intermediate education had lower consumption of *in natura*/minimally processed foods when compared to White men with lower education level, showing the impact of racism on diet. Absolute inequalities for the consumption of unhealthy foods presented a higher magnitude between Black/Brown men and women when compared to White men, which may drive inequalities in NCD. The increase in education could impact an expressive increase in the consumption of healthy foods in the Black/Brown population, and in the reduction in the consumption of unhealthy foods in White men, but without changes in Black/Brown women.

Data availability statement

The original contributions presented in this study are included in this article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the National Research Ethics Commission

(CONEP) of the National Health Council/Brazilian Ministry of Health: Certificate of Presentation and Ethical Appreciation (CAAE) number 65610017.1.0000.0008. The patients/participants provided their written informed consent to participate in this study.

Author contributions

BC and CA participated in the conception and design of the study, statistical analyses, data interpretation, and manuscript writing. RC and LO participated in the statistical analyses, data interpretation, manuscript writing, and review. LR, RL, RC, and ML participated in the interpretation of data, manuscript writing, and review. All authors carried out a critical review of the manuscript's important intellectual content, approved the submitted final version, agreed to be responsible for all aspects of the work, and ensuring that issues related to the accuracy or integrity of any part of the work are investigated and resolved appropriately.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1055532/full#supplementary-material

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EDITED BY
Raquel Mendonça,
Universidade Federal de Ouro Preto, Brazil

REVIEWED BY
Anelise Andrade De Souza,
Universidade Federal de Ouro Preto, Brazil
Adriano M. Pimenta,
Federal University of Paraná, Brazil

*CORRESPONDENCE
Maria Laura da Costa Louzada
✉ maria.laura.louzada@usp.br

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Changes in socioeconomic inequalities in food consumption among Brazilian adults in a 10-years period

Maria Laura da Costa Louzada[1,2]*, Janaína Calu Costa[3], Caroline dos Santos Costa[1,2], Andrea Wendt[4] and Catarina Machado Azeredo[5]

[1]Center of Epidemiological Studies in Nutrition and Health (NUPENS), University of São Paulo, São Paulo, Brazil, [2]School of Public Health, Department of Nutrition, University of São Paulo, São Paulo, Brazil, [3]International Center for Equity in Health, University of Pelotas, Pelotas, Brazil, [4]Postgraduate Program in Health Technology, Catholic University of Paraná, Curitiba, Brazil, [5]School of Medicine, Federal University of Uberlandia, Uberlandia, Brazil

Objective: To evaluate changes in socioeconomic inequalities in food consumption in Brazil over a 10-year period.

Methods: Data on 24-h recalls of adults (aged 20 years or more) from the 2008/9 ($n = 26,327$) and 2017/8 ($n = 37,689$). Brazilian Dietary Survey were analyzed. We used the Nova classification system to group food items and estimate the percentage of total energy from ultra-processed foods and plant-based natural or minimally processed foods. For sex and area of residence, we calculated the percentage points (p.p.) difference between the estimates for women and men, and rural and urban populations. Negative values indicate higher consumption among men or urban residents, positive values indicate higher consumption among women or rural residents, and zero indicates equality. For education and wealth levels we calculated the slope index of inequality (SII). The SII varies from −100 to 100, with positive values indicating higher consumption among more educated or wealthiest groups, negative values indicating higher consumption among less educated or poorest groups, and zero equality.

Results: Over the period, we observed a reduction in the percentage of total energy from plant-based natural/minimally processed foods from 13.0 to 12.2% and an increase in that of ultra-processed foods from 17.0 to 18.3%. The urban population and those in the wealthier and more educated groups presented higher consumption of ultra-processed foods and lower consumption of plant-based natural/minimally processed foods in both survey years. Over the 10-year period, there was an overall reduction of the socioeconomic inequalities, mainly explained by the greater increase in ultra-processed food consumption by the rural population and those from the poorest and less educated groups (difference for area −7.2 p.p. in 2008/9 and −5.9 p.p. in 2017/8; SII for education 17.7 p.p. in 2008/9 and 13.8 p.p. in 2017/8; SII for wealth 17.0 p.p. in 2008/9 and 11.2 p.p. in 2017/8).

Conclusion: Socioeconomic inequalities in food consumption decreased in Brazil, but it may lead to the overall deterioration of the dietary quality of the more vulnerable groups.

KEYWORDS

ultra-processed food, socioeconomic inequality, food consumption, time trend, survey

Introduction

Globally, food systems are experiencing rapid and drastic changes characterized by the reduction in the consumption of traditional meals based on natural or minimally processed foods and the increase in the consumption of highly processed ready-to-eat products (1, 2). These changes conflict with the recommendations of a diet that promotes human and planetary health, which comprises the avoidance of ultra-processed foods (3) and the consumption of a plant-based diet with a low to moderate amount of seafood and poultry and diverse combinations of fruits, vegetables, legumes, and whole grains (4). Consequently, losses are observed for nutrition, public health, and the environment, including increases in rates of obesity, diabetes, and cardiovascular diseases, in addition to increased carbon budgets, climate risks, and biodiversity impairment (5).

Food consumption is structurally conditioned by social inequality (6) and, therefore, not homogeneously distributed among individuals. Unequal access to economic resources, food supply and retail markets make those less economically privileged more vulnerable to a low-quality diet and an increased burden of its negative effects (7, 8). Thus, analyzing the global trend of food consumption may disguise differences among social groups over time.

The social gradient in food consumption in high-income countries shows a clear pattern of low-income individuals presenting a higher consumption of unhealthy food and lower consumption of healthy food compared to high-income individuals (8). In middle-income countries, some complex relations have been reported, with less educated individuals eating both less healthy food, such as fruits and vegetables, and unhealthy food, such as soft drinks, compared to those located upper in the social ladder (9, 10). A telephone-based study that evaluated the frequency of consumption of some food consumption markers of adults living in Brazilian state capitals only showed that, from 2008 to 2019, the consumption of fruits and vegetables was more frequent among those more educated. In the same study, it was observed an increase in educational inequality due to the increasing consumption of fruits and vegetables among those more educated, not followed by the less educated. On the other hand, the regular consumption of soft drinks was more frequent among those in the intermediate groups of education, and the educational inequality has decreased, due to a reduction in soft drinks consumption in all groups, especially among those more educated (9).

The assessment of inequality changes in food consumption over time is essential for health planning since it considers different patterns from population subsets, revealing groups in social disadvantage and consequently contributing to more effective interventions. Middle-income countries are of particular interest, due to their high social inequalities, limited resources, and high burden of non-communicable diseases. Moreover, the literature of food consumption inequality in middle-income countries tends to be limited to individuals living in highly urbanized areas, not reflecting the reality of the rural areas of the country and it has been based on limited food markers, which compromises the understanding of inequality in food consumption (11, 12). This reinforces the need to explore inequalities in different domains such as gender, education, area of residence and wealth in order to find the more vulnerable groups.

In the present study, we aimed to evaluate changes in socioeconomic inequalities in the consumption of ultra-processed and plant-based natural or minimally processed foods among Brazilian adults in a 10-years period.

Methods

Data used in this study are from the individual food consumption modules of two editions of the Brazilian Household Budget Surveys (in Portuguese, *Pesquisa de Orçamentos Familiares*—POF) carried out by the Brazilian Institute of Geography and Statistics from May 2008 to May 2009 (hereafter called POF 2008) and from July 2017 to July 2018 (hereafter called POF 2017) (13, 14).

Both surveys used complex clustered sampling procedures in two stages, with geographic and statistical stratifications of the primary sampling units, which correspond to the sectors or clusters of sectors based on the Brazilian Demographic Census. In the first stage, primary sampling units were selected with probability proportional to the number of households in each sector by simple random sampling. The selected primary sampling units were distributed uniformly throughout the four trimesters of the study, in order to reproduce, within each stratum, the seasonal variation in income, prices, and food purchase and consumption. Then, permanent private households were selected using simple random sampling without replacement within each of the primary sample units selected.

For the individual food consumption module, subsamples of households were randomly selected from the original survey samples and corresponded to 24.3% of the full sample in 2008 and 34.7% in 2017. Food consumption data were collected for all residents aged ten years and over. The subsamples are representative of the Brazilian population living in private households. For this study, only data from adults aged 20 years and over were analyzed (26,327 individuals in 2008 and 37,689 in 2017).

Information on food consumption was collected using two 24-h food records in 2008 and two 24-h food recalls in 2017, both on non-consecutive days. In the food records, individuals detailed all foods and drinks consumed on the day in question (over 24 h) and the quantities of each item, referring to household measures. The food records were reviewed at the household by the interviewer together with the participant, typing the data in a program specially developed for this research. In the 24-h food recalls, the participants were asked, in personal interviews, about all the foods and drinks consumed on the day prior to the interview. Data collection was conducted following a structured script, in sequential stages of questioning the food, employing the Automated Multiple-Pass Method, using a software specifically designed for this assessment. To allow comparability between databases, some harmonization strategies were applied, including database compatibility and reanalysis of the information from the 2008 survey using the same food composition table applied in the 2017 survey (15).

Food consumption

Food consumption variables were defined based on the NOVA food classification system (16): the percentage of total energy from ultra-processed foods (the unhealthy eating indicator) and the percentage of plant-based natural or minimally processed foods (the healthy eating indicator).

Ultra-processed foods include industrial formulations typically ready for consumption made of numerous ingredients, often obtained from high-yield crops, such as sugars and syrups, refined starches, oils and fats, and protein isolates, in addition to remains of intensive animal farming. These formulations are made to be visually attractive, have a seductive aroma, and very intense flavors, using sophisticated combinations of flavorings, dyes, emulsifiers, sweeteners, thickeners, and other additives that modify the sensory attributes. Examples are cookies, candies, salty snacks, soft drinks, artificial juices, and several ready-to-eat meals (16).

Natural or minimally processed foods are edible parts of plants or animals, mushrooms and algae, soon after their separation from nature or altered by industrial processes such as removal of inedible parts, dehydration, milling, pasteurization, freezing and other processes that do not involve the addition of other substances. Their main aim is to extend the life of grains (cereals), legumes (pulses), vegetables, fruits, nuts, milk, meat and other foods, enabling their storage for longer use, and often to make their preparation easier or more diverse. The set of plant-based natural or minimally processed food was defined based on international recommendations for a healthy and sustainable diet (4, 17, 18) and includes fruits (excluding juices), vegetables, legumes, nuts and seeds, and whole grains (excluding flour). In the analysis, both the composite indicator—based on the sum of the five food groups listed above—and the individual subgroups were used.

Socioeconomic variables

To assess inequalities in food consumption between population subgroups, four socioeconomic and demographic variables were used: sex (female, male), area of residence (urban, rural), education level (none, 1–4, 5–8, 9–11, 12–13, 14 or more years of education), and wealth quintiles (Q1–Poorest to Q5–Wealthiest). Following the methodology employed in international household and health surveys, the wealth quintiles are based on the wealth index, a composite measure of living standards calculated using data on household's ownership of selected assets (such as TV, radio, shower, bed, computer, and vehicles), materials used for construction, type of water access and sanitation facilities, etc. It was generated using principal component analysis and, from the factors resulting from the model, individual households were placed on a continuous scale of relative wealth (19). These standardized scores were then ranked and divided into five equally-sized groups, the wealth quintiles, with the first quintile representing the poorest 20% in the sample and the fifth quintile representing the wealthiest 20%.

Statistical analyses

We described the means and 95% confidence intervals (95% CI) for the food consumption indicators in 2008 and 2017 for the whole country. In order to describe inequalities according to each of the selected stratifiers, we presented the estimates using graphs called equiplots, which make it possible to visualize both the consumption estimates in each group and the distance between the categories, which represents absolute inequality. For the subgroups that are part of the set of plant-based natural or minimally processed foods, we described the mean and 95% CI for each survey according to the socioeconomic variables.

Simple and complex measures were used to address the magnitude of socioeconomic and demographic inequalities. For sex and area of residence, the binary variables, we calculated absolute inequality as the difference in percentage points (p.p.) between the estimates for women and men as well as for rural and urban areas. The estimates and respective 95% CI were obtained from linear regression models with men and urban area as reference categories, and its coefficient represents the gaps between the groups. Negative values indicate higher consumption among men, whereas positive values indicate higher consumption among women, and zero indicates equality. The same was obtained for area of residence, for which the estimate for urban area was subtracted from the estimate for rural area.

For education level and wealth quintiles, the ordinal variables, we calculated a complex measure to evaluate inequalities, the slope index of inequality (SII). This index is a measure of the difference in the outcomes between the top and the bottom groups, taking into account in its estimation the values for all intermediate categories as well as the size of each group. The index is the slope resulting from a linear regression model and expresses the absolute inequality in p.p.; it can vary from −100 to 100, with positive values indicating higher consumption among more educated or wealthiest groups, negative values indicating higher consumption among less educated or poorest groups, and zero indicating equality (20).

Evidence of differences in the estimates between the 2008 and the 2017 surveys was considered based on the non-overlapping of confidence intervals.

All analyses were performed in Stata 15® (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC) using expansion factors and sample weights with the *svy* prefix command for survey data analysis.

Results

Consumption of ultra-processed foods and plant-based natural or minimally processed foods

Estimates of the consumption of plant-based natural or minimally processed foods and of ultra-processed foods in 2008 and 2017 for the whole group of Brazilian adults are presented in Figure 1. Between the two surveys, a reduction in the average caloric contribution of the set of plant-based natural or minimally processed foods was observed, decreasing from 13.0% in 2008 to 12.2% in 2017. On the other hand, the consumption of ultra-processed foods increased from 17.0% in 2008 to 18.3% of total energy intake in 2017.

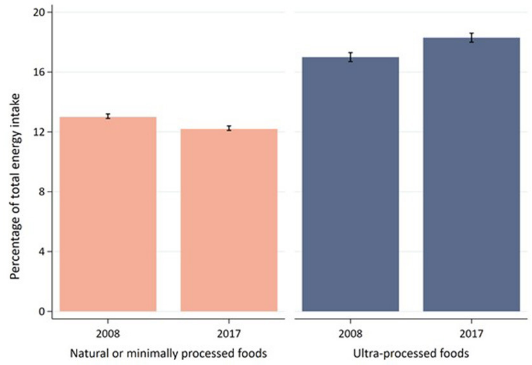

FIGURE 1
Percentage of total energy intake (mean and 95% confidence intervals) from the set of healthy foods and ultra-processed foods at the national level in 2008 and 2017 by Brazilian adults aged 20 years or more. Estimates for Healthy foods: 13.0, 95%CI 12.9; 13.2 (2008) and 12.2, 95%CI 12.1; 12.4 (2017); Estimates for Ultra-processed foods: 17.0, 95%CI 16.7; 17.3 (2008) and 18.3, 95%CI 18.0; 18.6 (2017). Evidence of differences in the estimates between the 2008 and the 2017 surveys was considered based upon the non-overlapping of confidence intervals.

In Figure 2, we present estimates of consumption for the set of plant-based natural or minimally processed foods and ultra-processed foods in both surveys according to sex, area of residence, education, and wealth quintiles and, in Table 1, the inequality measures for both indicators, by the same socioeconomic and demographic variables.

In 2008, the sex difference in the percentage of energy from the set of plant-based natural or minimally processed foods was −0.2 p.p., indicating a slightly higher consumption among men when compared to women. However, this pattern changed in 2017, as women presented a 0.3 p.p. higher consumption when compared to men. The caloric contribution of ultra-processed foods was higher for women in both surveys but there was a small reduction in the inequality in 2017 (difference of 2.0 p.p. in 2008 and 1.3 p.p. in 2017).

Differences between individuals living in urban and rural areas were small for the set of plant-based natural or minimally processed foods, with slightly higher consumption in the rural area in both 2008 and 2017 (difference in 2008 = 1.4 p.p.; difference in 2017 = 1.3 p.p.). An opposite pattern was observed for ultra-processed foods: their caloric contribution was higher for those living in urban areas in both surveys but there was a small reduction in the inequality in 2017 (difference of −7.2 p.p. in 2008 and −5.9 p.p. in 2017).

The consumption of the plant-based natural or minimally processed foods decreased as the education level increased in both surveys, indicated by negative values of SII. However, a small reduction in the inequality magnitude was observed

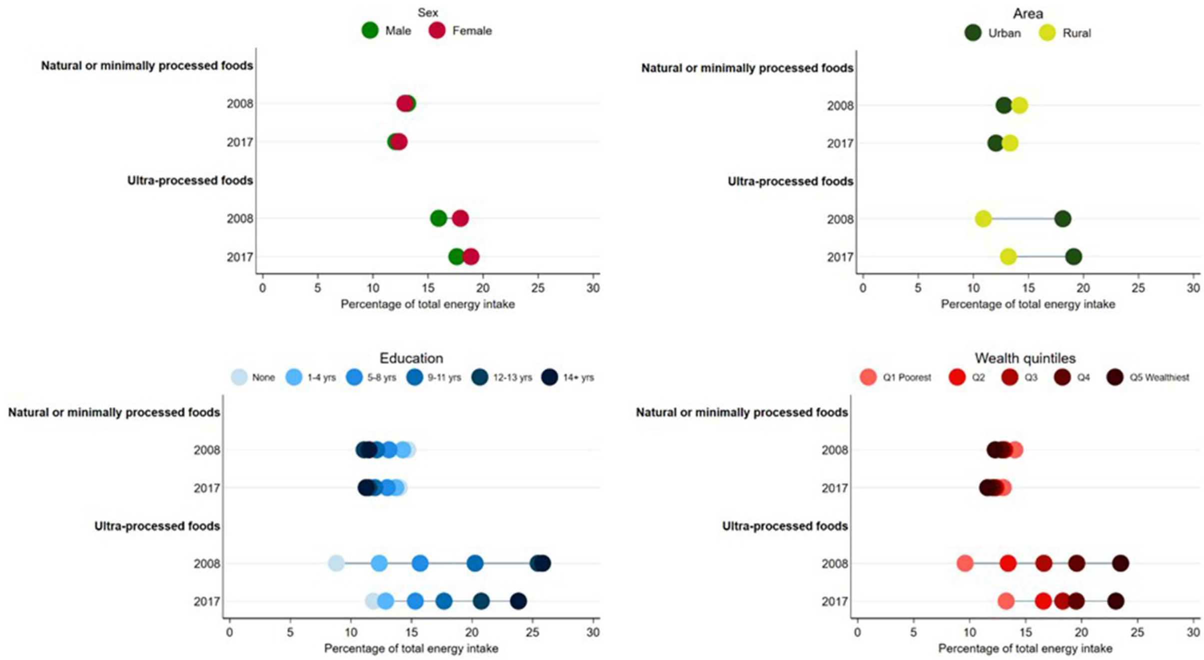

FIGURE 2
Percentage of total energy intake from the set of healthy foods and ultra-processed foods by sex, area of residence, education, and wealth quintiles in 2008 and 2017.

TABLE 1 Inequality measures for the set of plant-based natural or minimally processed foods and ultra-processed foods in 2008 and 2017.

	Difference[a] (percentage points)				Slope index of inequality[b] (percentage points)			
	2008		2017		2008		2017	
	Estimate	95%CI	Estimate	95%CI	Estimate	95%CI	Estimate	95%CI
Plant-based natural or minimally processed foods								
Sex	−0.2	−0.5; 0.0	0.3	0.1; 0.5[c]	-	-	-	-
Area	1.4	1.0; 1.8	1.3	1.0; 1.6	-	-	-	-
Education	-	-	-	-	−3.9	−4.5; −3.4	−3.3	−3.7; −2.8
Wealth quintiles	-	-	-	-	−1.9	−2.5; −1.3	−1.5	−2.0; −1.0
Ultra-processed foods								
Sex	2.0	1.5; 2.5	1.3	0.9; 1.7	-	-	-	-
Area	−7.2	−7.8; −6.6	−5.9	−6.4; −5.4[c]	-	-	-	-
Education	-	-	-	-	17.7	16.7; 18.8	13.8	12.9; 14.6[c]
Wealth quintiles	-	-	-	-	17.0	15.9; 18.2	11.2	10.2; 12.2[c]

[a]Difference (female—male, rural—urban) estimated for binary stratifiers.
[b]Slope index of inequality estimated for ordinal stratifiers.
[c]Evidence of differences in the estimates between the 2008 and the 2017 surveys was considered based upon the non-overlapping of confidence intervals.

between 2008 and 2017 (SII of −3.9 p.p. in 2008 and −3.3 p.p. in 2017). The opposite was observed for ultra-processed foods, for which the consumption was higher among individuals with higher education levels (SII in 2008 = 17.7 p.p.; SII in 2017 = 13.8 p.p.). Between 2008 and 2017, there was an increase in the consumption of ultra-processed foods among individuals with lower education levels (zero or 1–4 years of education) and a reduction among those with higher education levels (5–8 years, 9–11 years, 12–13 years, and 14 or more years) and, consequently, a reduction of the inequality.

Similarly, the consumption of the set of plant-based natural or minimally processed foods was inversely associated with wealth in both years and the magnitude of the inequality also slightly reduced (SII −1.9 p.p. in 2008 and −1.5 p.p. in 2017). Oppositely, the consumption of ultra-processed foods was higher among the wealthiest groups in comparison to the poorest. However, between 2008 and 2017, there was a reduction in the gap between the categories (SII of 17.0 p.p. in 2008 and 11.2 p.p. in 2017), due to an increase in the consumption of ultra-processed foods among the three more disadvantaged groups and a stabilization in the fourth and fifth quintiles.

Consumption of fruits, vegetables, pulses, nuts and seeds, and whole grains

Estimates of the consumption of each subgroup from the set of plant-based natural or minimally processed foods in 2008 and 2017 are presented in Table 2. For Brazilian adults as a whole, we observed a reduction in the consumption of fruits (from 4.0% in 2008 to 3.4% in 2017) and pulses (from 7.1% in 2008 to 6.5% in 2017) and a slightly increase in the consumption of vegetables (1.5% in 2008 to 1.8% in 2017). No differences were observed in the consumption of whole grains (0.3% in both surveys) and nuts and seeds (0.1% in and 0.2% in 2017, presenting overlapping confidence intervals).

For the subgroups of healthy foods, inequality measures are presented in Table 3. The estimates stratified by sex indicate that women consumed less calories from pulses and more from fruits and vegetables than men in both years. Absolute inequalities between males and females have changed between surveys for pulses, with a reduction of the difference from −1.6 p.p. to −1.3 p.p., whereas an increase in the difference was observed for vegetables, from 0.1 p.p. to 0.2 p.p.

The consumption of the fruits increased as the education and wealth level increased in both surveys while the opposite was observed for the consumption of pulses in both surveys. In addition, consumption of pulses was higher for those living in rural area. No significant changes in the inequality measures between 2008 and 2017 were observed for area of residence and educational levels. Consumption of pulses decreased according to wealth quintiles and the estimate of wealth-based inequalities, measured by the SII, decreased from −3.7 p.p. to −2.9 p.p.

Discussion

Our analysis showed a small but significant increase of 1.3 p.p. in the consumption of ultra-processed foods and a concomitant reduction of 1.2 p.p. in the contribution of the set of plant-based natural or minimally processed foods to the total diet between 2008 and 2017 among Brazilian adults. We observed that the urban population and those in the wealthier group and with higher education levels presented higher consumption of ultra-processed foods and lower consumption of plant-based natural or minimally processed foods in both survey years, whereas no expressive differences were observed by sex. These differences were much more prominent for the consumption of ultra-processed foods. However, over the 10-year period, there was an overall reduction of the socioeconomic inequalities and, therefore, a deterioration of the dietary quality of the more disadvantaged groups.

Ultra-processed foods have always been promoted and advertised incessantly with "seductive" messages that may led people to believe they are superior to traditional dishes like rice and beans and that they will make people happier (17). On the other hand, contrary to what happens in Global North countries, these foods have always been more expensive and more accessible in urbanized areas (21). As a consequence, the consumption of ultra-processed foods has been higher among wealthiest people in Brazil. However, reductions in the inequalities in their consumption can be explained by the expansion of the access to unhealthy foods by lower socioeconomic classes, which may be due to the reduction in their prices, the expansion of their offer in the most diverse purchase places and the increasing penetration of transnational food companies in more remote and rural areas of the country (22–24). Analysis of data from the National System of Consumer Price Indexes shows that, although ultra-processed foods are still more expensive than natural or minimally processed foods and culinary ingredients, since the early 2000s, an inversion trend in the prices has been observed (24). The price of natural or minimally processed foods and culinary ingredients increased continuously from 2003 to 2017 (from R$ 4.43/kg to R$ 4.70/kg). On the other hand, the price of ultra-processed foods showed an opposite trend, decreasing from R$ 7.31/kg to R$ 6.67/kg in the same period. In addition, the relative price of healthy foods in relation to unhealthy foods increased over the period, from 53% in 1995 to 70% in 2017 (24). More recent data indicate that, since 2020, this trend has been accelerating and that, soon, ultra-processed foods will be cheaper than other foods (25).

In recent years, there has also been an increase in the purchase of foods in supermarket chains and previous studies indicate that they offer a greater concentration of ultra-processed foods compared to other traditional shopping sites. In 2008-2009, there was a direct and significant relationship between the participation of supermarkets in total food acquisition and the consumption of ultra-processed foods by the Brazilian population (26). Specific marketing of ultra-processed foods to lower-income communities has also helped to accelerate their consumption growth in poorer segments

TABLE 2 Consumption of subgroups of the set of plant-based natural or minimally processed foods (as percentage of total energy intake) by sex, area of residence, education, and wealth quintiles in 2008 and 2017.

	Fruits (% and 95%CI)		Vegetables (% and 95%CI)		Pulses (% and 95%CI)		Nuts and seeds (% and 95%CI)		Whole grains (% and 95%CI)	
	2008	2017	2008	2017	2008	2017	2008	2017	2008	2017
Sex										
Male	3.4 (3.2; 3.5)	2.7 (2.7; 2.8)	1.5 (1.5; 1.5)	1.7 (1.7; 1.7)	7.9 (7.8; 8.1)	7.2 (7.0; 7.3)	0.1 (0.1; 0.2)	0.2 (0.2; 0.2)	0.2 (0.2; 0.3)	0.3 (0.2; 0.3)
Female	4.5 (4.4; 4.6)	4.0 (3.9; 4.1)	1.6 (1.6; 1.6)	1.9 (1.9; 1.9)	6.4 (6.2; 6.5)	5.9 (5.8; 6.0)	0.1 (0.1; 0.2)	0.3 (0.2; 0.3)	0.3 (0.2; 0.3)	0.3 (0.3; 0.4)
Area of residence										
Urban	4.0 (3.9; 4.1)	3.4 (3.3; 3.5)	1.6 (1.5; 1.6)	1.8 (1.8; 1.8)	6.9 (6.7; 7.0)	6.3 (6.2; 6.4)	0.1 (0.1; 0.2)	0.2 (0.2; 0.3)	0.2 (0.2; 0.3)	0.3 (0.3; 0.3)
Rural	3.9 (3.6; 4.1)	3.3 (3.1; 3.4)	1.5 (1.4; 1.5)	1.8 (1.7; 1.8)	8.4 (8.0; 8.8)	7.7 (7.5; 8.0)	0.1 (0.1; 0.2)	0.2 (0.2; 0.3)	0.3 (0.2; 0.4)	0.4 (0.3; 0.5)
Education										
None	3.7 (3.4; 3.9)	3.6 (3.3; 3.8)	1.6 (1.6; 1.7)	1.9 (1.8; 1.9)	9.1 (8.7; 9.4)	8.2 (7.9; 8.4)	0.0 (0.0; 0.1)	0.1 (0.1; 0.2)	0.3 (0.2; 0.4)	0.3 (0.2; 0.3)
1–4 years	3.9 (3.7; 4.1)	3.5 (3.3; 3.7)	1.6 (1.6; 1.7)	2.0 (1.9; 2.0)	8.4 (8.1; 8.6)	7.9 (7.6; 8.1)	0.1 (0.1; 0.1)	0.1 (0.1; 0.2)	0.3 (0.2; 0.3)	0.3 (0.2; 0.3)
5–8 years	3.7 (3.6; 3.9)	3.3 (3.2; 3.5)	1.5 (1.5; 1.6)	1.9 (1.8; 1.9)	7.6 (7.3; 7.8)	7.3 (7.2; 7.5)	0.1 (0.1; 0.1)	0.1 (0.1; 0.2)	0.2 (0.1; 0.2)	0.3 (0.2; 0.3)
9–11 years	3.9 (3.7; 4.0)	3.0 (2.8; 3.1)	1.5 (1.4; 1.5)	1.8 (1.7; 1.8)	6.4 (6.2; 6.6)	6.8 (6.6; 7.0)	0.2 (0.1; 0.2)	0.2 (0.1; 0.2)	0.2 (0.2; 0.3)	0.2 (0.2; 0.3)
12–13 years	4.1 (3.6; 4.5)	3.1 (3.0; 3.3)	1.4 (1.3; 1.5)	1.7 (1.7; 1.8)	5.1 (4.6; 5.5)	6.1 (6.0; 6.3)	0.3 (0.0; 0.5)	0.2 (0.2; 0.3)	0.3 (0.1; 0.4)	0.3 (0.2; 0.3)
14 years or more	4.9 (4.6; 5.2)	4.2 (4.0; 4.4)	1.6 (1.5; 1.6)	1.8 (1.7; 1.8)	4.5 (4.2; 4.7)	4.4 (4.3; 4.6)	0.2 (0.2; 0.3)	0.5 (0.4; 0.5)	0.3 (0.2; 0.4)	0.4 (0.3; 0.4)
Wealth quintiles										
Q1–Poorest	3.5 (3.3; 3.7)	3.0 (2.8; 3.1)	1.5 (1.4; 1.5)	1.7 (1.7; 1.8)	8.7 (8.3; 9.0)	7.7 (7.5; 7.9)	0.1 (0.1; 0.1)	0.2 (0.2; 0.3)	0.3 (0.2; 0.4)	0.4 (0.3; 0.4)
Q2	3.5 (3.3; 3.7)	3.1 (3.0; 3.3)	1.5 (1.5; 1.5)	1.8 (1.7; 1.8)	7.8 (7.5; 8.1)	7.0 (6.8; 7.2)	0.1 (0.0; 0.1)	0.2 (0.1; 0.2)	0.2 (0.2; 0.3)	0.3 (0.3; 0.3)
Q3	3.9 (3.7; 4.1)	3.4 (3.2; 3.5)	1.5 (1.5; 1.6)	1.8 (1.8; 1.9)	7.3 (7.0; 7.6)	6.6 (6.4; 6.8)	0.1 (0.1; 0.1)	0.1 (0.1; 0.2)	0.2 (0.2; 0.3)	0.3 (0.2; 0.4)
Q4	3.9 (3.7; 4.1)	3.5 (3.3; 3.7)	1.6 (1.6; 1.7)	1.9 (1.8; 1.9)	7.0 (6.7; 7.3)	6.3 (6.0; 6.5)	0.1 (0.1; 0.2)	0.2 (0.1; 0.2)	0.2 (0.1; 0.2)	0.2 (0.2; 0.3)
Q5–Wealthiest	4.7 (4.5; 5.0)	4.0 (3.8; 4.2)	1.6 (1.5; 1.6)	1.8 (1.7; 1.9)	5.4 (5.1; 5.7)	5.1 (4.9; 5.4)	0.2 (0.2; 0.3)	0.4 (0.3; 0.5)	0.3 (0.2; 0.4)	0.3 (0.2; 0.4)
Total	4.0 (3.8; 4.1)	3.4 (3.3; 3.5)	1.5 (1.5; 1.6)	1.8 (1.8; 1.8)	7.1 (7.0; 7.3)	6.5 (6.4; 6.6)	0.1 (0.1; 0.2)	0.2 (0.2; 0.2)	0.3 (0.2; 0.3)	0.3 (0.3; 0.3)

TABLE 3 Inequality measures for the set of plant-based natural or minimally processed foods subgroups in 2008 and 2017.

	Difference[a]				Slope index of inequality[b]			
	2008		2017		2008		2017	
	Estimate	95%CI	Estimate	95%CI	Estimate	95%CI	Estimate	95%CI
Fruits								
Sex	1.2	1.0; 1.3	1.3	1.1; 1.4	-	-	-	-
Area	−0.1	−0.4; 0.2	−0.2	−0.4; 0.0	-	-	-	-
Education	-	-	-	-	0.7	0.4; 1.1	0.5	0.3; 0.8
Wealth quintiles	-	-	-	-	1.5	1.1; 1.9	1.2	0.9; 1.5
Vegetables								
Sex	0.1	0.1; 0.1	0.2	0.1; 0.2[c]	-	-	-	-
Area	-0.1	−0.1; 0.0	0.0	−0.1; 0.0	-	-	-	-
Education	-	-	-	-	−0.2	−0.3; −0.1	−0.2	−0.3; −0.2
Wealth quintiles	-	-	-	-	0.2	0.1; 0.3	0.1	0.0; 0.2
Pulses								
Sex	−1.6	−1.7; −1.4	−1.3	−1.4; −1.1[c]	-	-	-	-
Area	1.5	1.1; 1.9	1.4	1.1; 1.7	-	-	-	-
Education	-	-	-	-	−4.7	−5.1; −4.3	−4.0	−4.3; −3.7
Wealth quintiles	-	-	-	-	−3.7	−4.3; −3.2	−2.9	−3.3; −2.5[c]
Nuts and seeds								
Sex	0.0	0.0; 0.1	0.1	0.0; 0.1	-	-	-	-
Area	0.0	−0.1; 0.0	0.0	−0.1; 0.0	-	-	-	-
Education	-	-	-	-	0.2	0.1; 0.3	0.3	0.3; 0.4
Wealth quintiles	-	-	-	-	0.2	0.1; 0.3	0.2	0.0; 0.3
Whole grains								
Sex	0.0	0.0; 0.1	0.1	0.0; 0.1	-	-	-	-
Area	0.1	0.0; 0.2	0.1	0.0; 0.2	-	-	-	-
Education	-	-	-	-	0.0	−0.1; 0.1	0.1	0.0; 0.2
Wealth quintiles	-	-	-	-	0.0	−0.1; 0.1	−0.1	−0.2; 0.0

[a] Difference (female—male, rural—urban) estimated for binary stratifiers.
[b] Slope index of inequality estimated for ordinal stratifiers.
[c] Evidence of differences in the estimates between the 2008 and the 2017 surveys was considered based upon the non-overlapping of confidence intervals.

of Brazilian society. Some of the "Big food" companies, for example, have implemented "popular positioning products" projects, which are targeted at low-income consumers and drive door-to-door sales of ultra-processed foods on the outskirts of several Brazilian cities, on trains and subway stations, in retail chains that sell electronics and appliances, and also in "floating supermarkets" that take these products to remote Amazonian communities (27).

Our results also showed that there are different patterns in the distribution of consumption of healthy food subgroups: while fruits are more consumed by people of higher socioeconomic conditions, the opposite is observed regarding the consumption of beans. On the other hand, our results also showed that the drop in the consumption of healthy foods is mainly driven by the trend of decreasing consumption of beans (−0.7 p.p.). This was accompanied by a reduction in wealth inequality, which means an even more accentuated decline in the consumption of this food group among the poorest. These data are extremely worrying considering that beans, combined with rice, are one of the most traditional foods in the Brazilian diet, making up a healthy and sustainable meal, in addition to being relatively cheap (17). In 2008, for example, the average price of beans was almost 60% lower than the average price of the entire set of natural or minimally processed foods (27) and the price of the group of pulses and cereals has not increased since 1995 (24). On the other hand, culinary preparations made of beans require more time and better cooking skills, which may be associated with the downward trend in their consumption. A recent study with data on household food purchases by Brazilian families showed that, unlike plant-based natural or minimally processed foods, unprocessed meats, especially red meats, followed the upward trend of ultra-processed foods in all income strata (28).

Telephone-based study carried out in Brazilian capitals only evaluated the frequency of consumption of some food consumption markers and also showed that the consumption of fruits was more prevalent among the more educated citizens, while beans were mostly consumed by the less educated. Oppositely, the consumption of soft drinks (an ultra-processed food) was more frequent among those in the intermediate groups of education (9). As far as we know, our study is the first evaluating inequalities in food consumption with a representative sample of the entire country, from both rural and urban areas, in which the food consumption was evaluated using a very comprehensive method of data collection—two 24-h food records in 2008 and two 24-h food recalls in 2017—and that evaluated a broad group of socioeconomic measures.

Our data raise a debate about the complexity of discussing socioeconomic inequalities in food consumption. While, for some important health outcomes, the reduction of the difference between groups defined by social characteristics represents better living conditions for all, this does not always seem true when it comes to food intake. The nutrition transition, characterized by the rise of a globalized food system dominated by the agribusiness and the "Big Food" companies, benefits from the increase in the purchasing power of populations while bringing as side effects chronic diseases that affect the poorer most intensely. This phenomenon is highly marked in middle-income countries like Brazil. It is important to point out that until 2014, Brazil had been showing a fundamental economic growth and improvement in the social conditions of its population, which may have reflected in the reduction of inequality in food consumption between the richest and poorest. After that, the country began suffering an economic recession and a political crisis, both of which exacerbated by the Covid-19 pandemic. Considering that this scenario significantly increased the food insecurity levels and worsened the nutrition conditions of the Brazilian population (29), our study can serve as a good "baseline" to assess the post-pandemic evolution of these indicators. It is necessary to politicize the debate on inequalities, advocating policies that not only increase the purchasing power of the population, but that protect people from unhealthy food environments, which includes the massive advertising of ultra-processed foods, and guarantee the right to nutritious, affordable and sustainably-produced foods.

We are aware that our study has some limitations, mainly related to potential biases inherent to dietary surveys, including the possibility of under or overestimation of the consumption of certain food groups; differences between real cooking recipes and standardized recipes; and differences between the real nutritional composition of the foods consumed and that from the nutritional composition table. However, data collection instruments were pre-tested and validated and inconsistent records were excluded and replaced with imputed values, after quality control. In addition, the food nutritional composition table used to calculate energy was built specifically for the Brazilian population, and food consumption estimates were adjusted by the Multiple Source Method to account for the variability of the 2 days of consumption. Finally, it is important to highlight that different methods were applied to collect food consumption information in the two surveys (food records in 2008 and 24 h food recalls in 2017). Nevertheless, a previous publication showed that these changes, in general, had little effect on the estimation of diet composition, allowing comparison between the two databases after harmonization strategies (databases were made compatible and the information from the 2008 survey was reanalyzed using the same food composition table used in the 2017 survey) (15). On the other hand, the strengths of this study include the rigorously probabilistic nature of the samples analyzed and the national representativeness, ensured by the inclusion of more than 70 thousand people living in urban and rural areas from all the regions of the country, and also the availability of a database with more than 1,800 food items. Besides that, the use of absolute, relative and complex measures of inequality brings a robustness to the estimates and conclusions. The slope index of inequality, for example, measures the absolute inequality of the indicator between the most privileged individuals and the less privileged individuals, taking into consideration the entire distribution of the stratification variable (30).

In conclusion, our results showed marked socioeconomic inequalities in food consumption among Brazilian adults, mainly in the ultra-processed food consumption. However, contrary to expectations, a reduction of the socioeconomic inequalities may lead to the overall deterioration of the dietary quality of the more disadvantaged groups.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.ibge.gov.br/.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

JC and AW run data analyses. All authors were responsible for planning the analyses, interpreting the results, and writing the paper. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Raquel Mendonça,
Universidade Federal de Ouro Preto,
Brazil

REVIEWED BY
Marialaura Bonaccio,
Mediterranean Neurological Institute
Neuromed (IRCCS), Italy
Nancy Babio,
University of Rovira i Virgili, Spain

*CORRESPONDENCE
Inge Huybrechts
huybrechtsl@iarc.fr

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Characterization of the degree of food processing in the European Prospective Investigation into Cancer and Nutrition: application of the Nova classification and validation using selected biomarkers of food processing

Inge Huybrechts[1]*, Fernanda Rauber[2,3], Geneviève Nicolas[1], Corinne Casagrande[1], Nathalie Kliemann[1], Roland Wedekind[1], Carine Biessy[1], Augustin Scalbert[1], Mathilde Touvier[4], Krasimira Aleksandrova[5,6], Paula Jakszyn[7,8], Guri Skeie[9], Rashmita Bajracharya[10], Jolanda M. A. Boer[11], Yan Borné[12], Veronique Chajes[1], Christina C. Dahm[13], Lucia Dansero[14], Marcela Guevara[15,16,17], Alicia K. Heath[18], Daniel B. Ibsen[13,19,20,21], Keren Papier[22], Verena Katzke[10], Cecilie Kyrø[23], Giovanna Masala[24], Esther Molina-Montes[25,26,27,28], Oliver J. K. Robinson[29], Carmen Santiuste de Pablos[26,30], Matthias B. Schulze[31,32], Vittorio Simeon[33], Emily Sonestedt[12], Anne Tjønneland[23], Rosario Tumino[34], Yvonne T. van der Schouw[35], W. M. Monique Verschuren[11,35], Beatrice Vozar[1], Anna Winkvist[36,37], Marc J. Gunter[1], Carlos A. Monteiro[3,38], Christopher Millett[2,39] and Renata Bertazzi Levy[2,3]

[1]Nutrition and Metabolism Branch, International Agency for Research on Cancer, Lyon, France, [2]Department of Preventive Medicine, School of Medicine, University of São Paulo, São Paulo, Brazil, [3]Center for Epidemiological Research in Nutrition and Health, University of São Paulo, São Paulo, Brazil, [4]Sorbonne Paris Nord University, INSERM U1153, INRAE U1125, CNAM, Nutritional Epidemiology Research Team (EREN), Epidemiology and Statistics Research Center, University Paris Cité (CRESS), Paris, France, [5]Department of Epidemiological Methods and Etiological Research, Leibniz Institute for Prevention Research and Epidemiology (BIPS), Bremen, Germany, [6]Human and Health Sciences, University of Bremen, Bremen, Germany, [7]Unit of Nutrition and Cancer, Cancer Epidemiology Research Programme, Catalan Institute of Oncology (ICO-IDIBELL), Barcelona, Spain, [8]Blanquerna School of Health Sciences, Ramon Llull University, Barcelona, Spain, [9]Department of Community Medicine, UiT the Arctic University of Norway, Tromsø, Norway, [10]German Cancer Research Center (DKFZ), Heidelberg, Germany, [11]Centre for Nutrition, Prevention and Health Services, National Institute for Public Health and the Environment (RIVM), Bilthoven, Netherlands, [12]Department of Clinical Sciences Malmö, Faculty of Medicine, Nutritional Epidemiology, Lund University, Lund, Sweden, [13]Department of Public Health, Aarhus University, Aarhus, Denmark, [14]Department of Clinical and Biological Sciences, Centre for Biostatistics, Epidemiology, and Public Health (C-BEPH), University of Turin, Turin, Italy, [15]Instituto de Salud Pública de Navarra, Pamplona,

Spain, [16]Centro de Investigación Biomédica en Red de Epidemiología y Salud Pública (CIBERESP), Madrid, Spain, [17]Navarra Institute for Health Research (IdiSNA), Pamplona, Spain, [18]Department of Epidemiology and Biostatistics, School of Public Health, Imperial College London, London, United Kingdom, [19]Steno Diabetes Center Aarhus, Aarhus, Denmark, [20]MRC Epidemiology Unit, University of Cambridge School of Clinical Medicine, Cambridge, United Kingdom, [21]Department of Nutrition, Exercise and Sports, University of Copenhagen, Frederiksberg, Denmark, [22]Cancer Epidemiology Unit, Nuffield Department of Population Health, University of Oxford, Oxford, United Kingdom, [23]Danish Cancer Society Research Center, Danish Cancer Society, Copenhagen, Denmark, [24]Clinical Epidemiology Unit, Institute for Cancer Research, Prevention and Clinical Network (ISPRO), Florence, Italy, [25]Department of Nutrition and Food Science, Campus of Cartuja, University of Granada, Granada, Spain, [26]CIBER of Epidemiology and Public Health (CIBERESP), Madrid, Spain, [27]Instituto de Investigación Biosanitaria ibs.GRANADA, Granada, Spain, [28]Biomedical Research Centre, Institute of Nutrition and Food Technology (INYTA) "José Mataix", University of Granada, Granada, Spain, [29]MRC Centre for Environment and Health, School of Public Health, Imperial College London, London, United Kingdom, [30]Department of Epidemiology, Murcia Regional Health Council, IMIB-Arrixaca, Murcia, Spain, [31]Department of Molecular Epidemiology, German Institute of Human Nutrition Potsdam-Rehbruecke, Nuthetal, Germany, [32]Institute of Nutritional Science, University of Potsdam, Potsdam, Germany, [33]Dipartimento di Salute Mentale e Fisica e Medicina Preventiva, Vanvitelli University, Naples, Italy, [34]Hyblean Association for Epidemiological Research, AIRE ONLUS, Ragusa, Italy, [35]Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, Utrecht University, Utrecht, Netherlands, [36]Sustainable Health, Department Public Health and Clinical Medicine, Umeå University, Umeå, Sweden, [37]Department of Internal Medicine and Clinical Nutrition, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden, [38]Department of Nutrition, School of Public Health, University of São Paulo, São Paulo, Brazil, [39]Public Health Policy Evaluation Unit, School of Public Health, Imperial College London, London, United Kingdom

Background: Epidemiological studies have demonstrated an association between the degree of food processing in our diet and the risk of various chronic diseases. Much of this evidence is based on the international Nova classification system, which classifies food into four groups based on the type of processing: (1) Unprocessed and minimally processed foods, (2) Processed culinary ingredients, (3) Processed foods, and (4) "Ultra-processed" foods (UPF). The ability of the Nova classification to accurately characterise the degree of food processing across consumption patterns in various European populations has not been investigated so far. Therefore, we applied the Nova coding to data from the European Prospective Investigation into Cancer and Nutrition (EPIC) in order to characterize the degree of food processing in our diet across European populations with diverse cultural and socio-economic backgrounds and to validate this Nova classification through comparison with objective biomarker measurements.

Methods: After grouping foods in the EPIC dataset according to the Nova classification, a total of 476,768 participants in the EPIC cohort (71.5% women; mean age 51 [standard deviation (SD) 9.93]; median age 52 [percentile (p)25–p75: 58–66] years) were included in the cross-sectional analysis that characterised consumption patterns based on the Nova classification. The consumption of food products classified as different Nova categories were compared to relevant circulating biomarkers denoting food processing, measured in various subsamples (N between 417 and 9,460) within the EPIC cohort via (partial) correlation analyses (unadjusted and adjusted by sex, age, BMI and country). These biomarkers included an industrial transfatty acid (ITFA) isomer (elaidic acid; exogenous fatty acid generated during oil hydrogenation and heating) and urinary 4-methyl syringol sulfate (an indicator for the consumption of smoked food and a component of liquid smoke used in UPF).

Results: Contributions of UPF intake to the overall diet in % grams/day varied across countries from 7% (France) to 23% (Norway) and their contributions to overall % energy intake from 16% (Spain and Italy) to >45% (in the UK and Norway). Differences were also found between sociodemographic groups; participants in the highest fourth of UPF consumption tended to be younger, taller, less educated, current smokers, more physically active, have a higher reported intake of energy and lower reported intake of alcohol. The UPF pattern as defined based on the Nova classification (group 4;% kcal/day) was positively associated with blood levels of industrial elaidic acid (r = 0.54) and 4-methyl syringol sulfate (r = 0.43). Associations for the other 3 Nova groups with these food processing biomarkers were either inverse or non-significant (e.g., for unprocessed and minimally processed foods these correlations were −0.07 and −0.37 for elaidic acid and 4-methyl syringol sulfate, respectively).

Conclusion: These results, based on a large pan-European cohort, demonstrate sociodemographic and geographical differences in the consumption of UPF. Furthermore, these results suggest that the Nova classification can accurately capture consumption of UPF, reflected by stronger correlations with circulating levels of industrial elaidic acid and a syringol metabolite compared to diets high in minimally processed foods.

KEYWORDS

food processing, Nova, EPIC, biomarkers, elaidic acid, syringol

Introduction

Worldwide there has been a dramatic increase in the production of industrially processed foods which has coincided with a growing prevalence of obesity, metabolic disorders and multiple chronic diseases (1–16). Global industrialisation, during which diets have been shifting from fresh unprocessed and minimally processed foods toward an increase in the consumption of "ultra-processed" foods (UPF), has been implicated as an important driver of these worrying trends in metabolic disease. UPF that undergo multiple physical, biological, and/or chemical processes, generally contain various processing contaminants, food additives or other industrial substances (17, 18), while they are on average poorer in protective micronutrients (e.g., anti-oxidants) compared to fresh foods (19–33).

The Nova classification system was developed in response to the increased recognition of the importance of classifying foods according to their degree and purpose of processing (i.e., un/minimally processed, processed and ultra-processed foods, as well as culinary ingredients) rather than in terms of nutrients (17, 34, 35). However, recent publications criticized the concepts and definitions used for the Nova classification (36–38), requesting further validation of this food processing classification. While consistent epidemiological evidence linking the consumption of UPF (Nova group 4) to adverse health outcomes such as obesity, type 2 diabetes, cardiovascular diseases, and some cancers is accumulating (3–16), an in depth validation of the Nova classification through comparison with food processing biomarkers is indeed still lacking in population studies.

The European Prospective Investigation into Cancer and Nutrition (EPIC) study offers an appropriate framework to investigate the validity of the Nova classification through comparison with food processing biomarkers already available, namely industrial trans-fatty acids (ITFA) measured in blood (39) and a methylsyringol metabolite measured in urine (40). UPF are the main source of industrially transformed fats, such as partially hydrogenated fats containing industrial trans-fatty acids (ITFA) (11, 41, 42). As such, ITFA profiles in blood may represent a reliable biomarker for UPF consumption. Also, the urinary biomarker 4-methylsyringol sulfate, can be used as an indicator for the consumption of smoked food as it is the human metabolite of 4-methyl syringol, which is formed by the combustion of wood during smoking and deposited on smoked foods (40) and often added as part of liquid smoke to UPF (such as hot dogs) to generate a smoky flavor. A previous intervention study (40) confirmed that syringol markers in urine were detected after intake of ultra-processed hot dogs and to a lower extent after intake of bacon (40). These differences observed after consumption of hot dogs and bacon might be explained by the use of liquid smoke in ultra-processed hot dogs.

The consumption of products from the different Nova categories in relation to relevant biomarkers that are related to food processing such as circulating ITFA has not been evaluated so far (11, 41). To address this gap, we aimed to evaluate UPF consumption patterns in relation to food processing biomarkers available in EPIC as objective indicators of dietary intakes. We hypothesize a positive association of the consumption of UPF with ITFA profiles in blood and syringol markers in urine.

Materials and methods

Cohort description

EPIC is a multi-center prospective cohort study, designed to investigate the relationship between nutrition and cancer, among other diseases. A detailed description of the EPIC cohort, including study populations and data collection, has been previously described elsewhere (43). Briefly, it consists of 23 study centers in 10 European countries, including, Denmark, France, Germany, Greece, Italy, Netherlands, Norway, Spain, Sweden, and the United Kingdom. Participants were mostly from the general population and recruited between 1991 and 2000. All participants provided written informed consent and the ethical review boards from the International Agency for Research on Cancer (IARC) and all local centers approved the study. Data from Greece were not available for these analyses.

At baseline, information on lifestyle, dietary intake and medical information as well as sociodemographic and anthropometric data were collected. Lifestyle and medical history questionnaires were used to obtain information on education, smoking status and intensity, alcohol consumption, diabetes and women's health (including menopausal status, oral contraceptive use, hormone replacement therapy use, age at menarche and age at first full-term pregnancy). Physical activity levels were estimated using a questionnaire focused on past-year physical activity in occupational, leisure and household domains and classified according to the validated Cambridge physical activity index (44).

Body weight and height were measured in all centers, except for Oxford (UK), France and Norway where these were self-reported. Anthropometric characteristics were measured by trained observers using standardized methods (43, 45). Weight and height were used to calculate body mass index (BMI) defined as weight in kilograms divided by height in meters squared (kg/m^2).

Diet was assessed at study baseline using validated country/center-specific methods, including dietary questionnaires (DQs) spanning the previous 12 months (43). In most centers, DQs were self-administered, with the exception of Ragusa (Italy), Naples (Italy) and Spain, where face-to-face interviews were performed. Extensive quantitative DQs were used in northern Italy, and Germany that were structured by meals in Spain, France and Ragusa. Semi-quantitative food-frequency questionnaires (FFQs) were used in Denmark, Netherlands, Norway, Italy, Umeå (Sweden) and the United Kingdom, while a FFQ was combined with a 7-day record on hot meals in Malmö (Sweden). Relying on a common food classification and standard handling of recipes, post-harmonization of all the questionnaire data was done by following standardized procedures (e.g., decomposing local recipes and complex foods into ingredients) to obtain a standardized food list for which the level of detail is more comparable between countries (except for Malmö and Spain where open dietary intake assessment methods were used with a higher level of detail; see **Supplementary Table 1** for overview of dietary assessment methods used in the different countries/centers). This standardized food list includes more than 11,000 food items. No brand name information was available in the EPIC dietary questionnaires, although some centers asked for the most frequent brand names or product names, e.g., for breakfast cereals in the UK and for margarines in the Netherlands.

From the initial pool of 521,323 EPIC participants, we excluded subjects with missing dietary and/or lifestyle information (n = 6,837), Greek participants (N = 28,034) due to data access issues, and 9,684 participants in the top or bottom 1% of the ratio of energy intake to energy requirement, leaving a final sample of 476,768 adults.

Nova classification

We classified all recorded food items from the EPIC questionnaires according to the Nova food classification system based on the nature, extent, and purpose of industrial food processing (17, 35). This coding was done in close collaboration with the team of Dr. Carlos Monteiro, University of São Paulo (USP), the founder of the Nova classification system. In summary, the Nova classification includes four processing groups and subgroups were adapted to the EPIC items (see **Supplementary Table 2**).

(1) Group 1: unprocessed or minimally processed foods, which are natural foods (edible parts of plants or of animals after separation from nature) and natural foods altered by methods such as freezing, pasteurization, fermentation, grinding, and other methods that do not include the addition of substances such as salt, sugar and/or oils or fats (e.g., fresh, dry or frozen fruits or vegetables; grains, flours and pasta; pasteurized/sterilized or powdered plain milk; plain yogurt; fresh or frozen meat);
(2) Group 2: processed culinary ingredients are extractions of fresh foods or elements of nature, including substances obtained directly from group 1 foods or from nature by processes that include pressing, refining, grinding, milling, and drying, and consumed in combination with group 1 foods in freshly prepared dishes (e.g., table sugar; oils; butter; cream and salt);

(3) Group 3: processed foods, which are products manufactured industrially with the addition of culinary ingredients (e.g., salt, sugar, oil or fats) to unprocessed or minimally processed foods. Examples of Nova group 3 include canned vegetables; traditional cheese; traditional bread; smoked fish; plain sweetened yogurt;
(4) Group 4: ultra-processed foods, which are commercial food and drink formulations containing besides salt, sugar or fats other substances derived from foods but not domestically used as culinary ingredients (such as protein isolates, hydrogenated oils, modified starches), flavors or additives designed to make the final product palatable or more appealing, such as colors, sweeteners, and emulsifiers. Examples of Nova group 4 include industrially produced bread, poultry and fish nuggets and sticks and other reconstituted meat products transformed with addition of preservatives other than salt; instant noodles and dehydrated soups; carbonated diet and regular sodas; chocolate with emulsifiers, chewing gums and candies with dyes (confectionery); margarine; instant desserts; most breakfast "cereals," "energy" bars; "energy" drinks; flavored milk drinks/yogurts; sweet desserts made from fruit with added sugars, artificial flavors and texturizing agents; cooked seasoned vegetables with ready-made sauces; vegetable patties (meat substitutes) containing food additives; "health" and "slimming" products such as powdered or "fortified" meal and dish substitutes (see **Supplementary Table 2**).

We identified homemade and artisanal food preparations, based on FFQ food names and/or local habits. Those identified as homemade recipes were decomposed using local recipes, and the Nova classification was applied to their ingredients. This disaggregation in ingredients was essential to correctly assess the consumption of culinary ingredients (Nova group 2). For breads, data from the Low Energy Ovens Project (46) were used at the country level and a visual check was performed at the DQ item level (e.g., usual Italian and French breads were considered artisanal, while UK bread was classified as ultra-processed). The very detailed EPIC 24-h recalls calibration data (47) and the website Open Food Facts[1] were also considered as sources of information on the degree of processing in the different EPIC countries (48).

The transition of food processing over the past decades: Creation of scenarios

Changes in the practice of food processing over the past decades require the use of different scenarios when classifying foods according to the Nova classification in a long-term follow-up cohort like EPIC. Dietary intakes were collected at baseline, while the food environment has changed in the intervening years, exposing the EPIC participants to potentially different degrees of food processing over the course of their follow-up (e.g., certain products that were still prepared at home during the 1990s have been replaced by industrial products). As such, a particular food item can potentially be classified in different Nova groups depending on the time period. Therefore, we created three possible scenarios. The "most likely scenario," in food safety terminology often called the middle bound scenario (MB), which is the scenario considering the most common food processing environment around the baseline period, was used as the main scenario (as agreed upon between the USP team and the IARC team). However, as we were unsure about the level of processing for some of the food items (e.g., when insufficient level of detail was available) for the period 1990–2020, we decided to introduce two alternative scenarios, namely a lower bound (LB) scenario reflecting the lowest degree of processing, and a more processed or upper bound (UB) scenario. For the lower bound scenario, some foods were classified in a less processed Nova group compared to the middle bound scenario when the food item may also have been prepared at home or in an artisanal setting instead of being industrially produced. For the upper bound scenario, some food items were classified in a more processed Nova group compared to the middle bound scenario when it was possible that the food item could be more processed than the most likely option assigned in the middle bound scenario. An example of these three scenarios used for the Nova classification is given in **Supplementary Table 3**.

Quality controls to evaluate the performance of the Nova classification in the European Prospective Investigation into Cancer and Nutrition

The coding of the Nova classification has been evaluated and checked via different quality controls (e.g., comparing the Nova coding proposed by independent food coders, systematic and logic quality controls, checking if the sum of Nova subgroups is equal to the attached Nova group, etc.). One of the quality controls was the comparison with an independent coding performed by the Spanish team in Barcelona on their food list from the Spanish EPIC cohort. The Nova coding performed by the international team was compared with the coding applied in Spain for the Spanish food list. Differences between these two classifications have been discussed between the two teams and few corrections to the three scenarios were made based upon this quality control.

1 https://fr.openfoodfacts.org/

Evaluation of the Nova classification through comparison with processing biomarkers

To evaluate the validity of the Nova classification in EPIC, we investigated correlations between the different Nova categories and food processing biomarkers available in subsets of EPIC participants (calibration study and nested case-control studies) analysed in biospecimens collected around the time that the baseline questionnaires were collected. ITFA (elaidic acid levels) measured in plasma phospholipids (49) have been used as biomarkers of dietary intake of industrial trans-fat which is mainly found in UPFs (according to Nova, the presence in the list of ingredients of partially hydrogenated oils, which provide industrial trans fats, makes the product be classified as ultra-processed). Fatty acid profiling was performed using a method previously described (49). ITFA was quantified using an Agilent 7890 gas chromatograph instrument (Agilent Technologies, Santa Clara, CA, USA), and concentrations were expressed as the percentage of total fatty acids ($n = 9{,}460$). Elaidic acid was the only ITFA measured in EPIC and as such used as a biomarker for industrially produced foods in these validation analyses.

4-Methyl syringol sulfate which has recently been proposed as a biomarker of smoked meat intake (40) was measured in 24 h urine samples (n = 417) from the EPIC calibration study that included samples from Italy, France and Germany. Sample preparation, laboratory measurement and data processing is described elsewhere (40).

Statistical analysis

All analyses were performed using the three scenarios for the Nova classification (the lower, middle and upper bound scenarios, representing changes in the food environment over time). Baseline characteristics were examined for the total population and by sex-specific quartiles of each Nova food group. The potential differences between participants were assessed using analysis of variance or $\chi 2$ tests when appropriate. Descriptive analyses were performed for each Nova food group considering their daily actual and relative intake in grams and kcal.

Pearson correlations were used to evaluate the association between the Energy % from UPF obtained via the Nova coding performed by the Spanish team (considered as the middle bound scenario) versus those obtained via the three codings performed by the international team for the Spanish food list. In addition, weighted kappa statistics were used to investigate agreement between these two independent codings of the Spanish food list.

Pearson and Spearman correlations were used to investigate associations of levels of biomarkers with % grams and % energy derived from the four Nova groups. Sensitivity analyses were run using partial correlations adjusted for sex, age, BMI and country.

In addition, we also ran sensitivity analyses for the Nova 3 and Nova 4 groups while excluding the alcoholic beverages from these two Nova groups in order to investigate associations between the Nova group intakes and the food processing biomarkers while eliminating the effect of alcohol.

Data availability

EPIC data and biospecimens are available for investigators who seek to answer important questions on health and disease in the context of research projects that are consistent with the legal and ethical standard practices of IARC/WHO and the EPIC centres. The primary responsibility for accessing the data, including the Nova categories obtained in the frame of the present publication, belongs to the EPIC centres that provided them. The use of a random sample of anonymised data from the EPIC study can be requested by contacting epic@iarc.fr. The request will then be passed to members of the EPIC Steering Committee for deliberation.

Results

A total of 476,768 participants were included in the analysis (71.5% women) investigating characteristics of the degree of food processing in EPIC. The mean and median age of participants at recruitment were 51 (SD 9.93) years and 52 (p_{25-75}: 58–66) years, respectively (**Table 1**). **Supplementary Table 4** presents the distributions of the different Nova groups for the total EPIC cohort using the three different scenarios and expressed in both grams and kcal (absolute and relative values) per day. A visual presentation is given in **Figure 1**. When looking at intakes expressed as grams per day, most of the intakes are from Nova group 1 (Nova group 1 intake is more than 6 times the amount of the processed and UPF groups), while the contributions from the processed and ultra-processed foods (Nova groups 3 and 4) are rather comparable, and Nova group 2 contributing less. The intakes expressed as kcal are rather comparable between the Nova groups 1, 3 and 4, while far lower for Nova group 2 (culinary ingredients). UPF intake contributed to 14% of the total diet in grams/day and to 32% of total daily energy intake. Differences in the consumption of ultra-processed foods were found between socio-demographic groups (**Table 1**). Although there was a higher proportion of women in this cohort, the contribution of UPF to the overall diet was very similar between men and women. Compared with the lowest fourth of UPF consumption, participants in the highest fourth of UPF consumption tended to be younger, taller, more often current smokers, more physically active, have a lower level of attained education, higher intakes of energy, fat and carbohydrates and lower intake of alcohol (see **Table 1**). In addition, the FSAm-NPS Dietary Index (DI) score (50), for which a higher score reflects an overall lower nutritional quality

TABLE 1 Baseline characteristics by sex-specific quartiles of relative intakes of Nova group 4 – ultra-processed foods (% g/day and % kcal/day including alcohol).

Characteristics	Nova group 4 quartiles in %g/d								Nova group 4 quartiles in %kcal/d							
	1st		2nd		3rd		4th		1st		2nd		3rd		4th	
	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)
Sex [*n* (%)]																
Male	33,982	(28.5)	33,982	(28.5)	33,983	(28.5)	33,982	(28.5)	33,982	(28.5)	33,982	(28.5)	33,983	(28.5)	33,982	(28.5)
Female	85,209	(71.5)	85,210	(71.5)	85,210	(71.5)	85,210	(71.5)	85,209	(71.5)	85,210	(71.5)	85,210	(71.5)	85,210	(71.5)
Age, years [mean (SD)]	53.0	(7.8)	52.6	(8.9)	51.3	(10.2)	48.3	(11.2)	51.7	(7.8)	51.3	(9.3)	51.6	(10.4)	50.7	(11.2)
Height, cm [mean (SD)]	164.2	(8.6)	166.0	(8.9)	166.8	(8.8)	167.6	(8.5)	163.2	(8.4)	166.2	(9.2)	167.5	(8.6)	167.7	(8.3)
BMI, kg/m^2 [mean (SD)]	25.4	(4.3)	25.2	(4.1)	25.2	(4.1)	25.2	(4.3)	25.5	(4.4)	25.1	(4.1)	25.2	(4.1)	25.2	(4.2)
Education [*n* (%)]																
None	8,806	(7.4)	3,187	(2.7)	2,275	(1.9)	1,676	(1.4)	11,083	(9.3)	3,268	(2.7)	1,055	(0.9)	538	(0.5)
Primary school completed	32,359	(27.1)	30,343	(25.5)	28,176	(23.6)	26,527	(22.3)	35,957	(30.2)	26,927	(22.6)	26,547	(22.3)	27,974	(23.5)
Technical/professional school	14,833	(12.4)	26,155	(21.9)	32,006	(26.9)	36,636	(30.7)	10,794	(9.1)	23,641	(19.8)	35,533	(29.8)	39,662	(33.3)
Secondary school	30,779	(25.8)	25,207	(21.1)	21,854	(18.3)	21,937	(18.4)	31,626	(26.5)	28,481	(23.9)	21,509	(18.0)	18,161	(15.2)
Longer education	29,776	(25.0)	30,712	(25.8)	29,079	(24.4)	25,884	(21.7)	27,504	(23.1)	33,880	(28.4)	29,623	(24.9)	24,444	(20.5)
Not specified	2,638	(2.2)	3,588	(3.0)	5,803	(4.9)	6,532	(5.5)	2,227	(1.9)	2,995	(2.5)	4,926	(4.1)	8,413	(7.1)
Smoking status [*n* (%)]																
Never	60,559	(50.8)	57,817	(48.5)	56,714	(47.6)	56,548	(47.4)	63,901	(53.6)	60,537	(50.8)	54,407	(45.6)	52,793	(44.3)
Former	30,197	(25.3)	33,231	(27.9)	34,381	(28.8)	32,815	(27.5)	27,842	(23.4)	32,369	(27.2)	35,801	(30.0)	34,612	(29.0)
Current	25,728	(21.6)	26,222	(22.0)	26,153	(21.9)	27,255	(22.9)	24,973	(21.0)	24,102	(20.2)	27,097	(22.7)	29,186	(24.5)
Unknown	2,707	(2.3)	1,922	(1.6)	1,945	(1.6)	2,574	(2.2)	2,475	(2.1)	2,184	(1.8)	1,888	(1.6)	2,601	(2.2)
Smoking intensity [*n* (%)]																
Never	46,551	(39.1)	48,903	(41.0)	51,975	(43.6)	54,501	(45.7)	48,482	(40.7)	49,733	(41.7)	51,504	(43.2)	52,211	(43.8)
Current, 1–15 cig/day	11,806	(9.9)	13,894	(11.7)	14,388	(12.1)	15,555	(13.1)	11,440	(9.6)	12,985	(10.9)	15,202	(12.8)	16,016	(13.4)
Current, 16–25 cig/day	7,155	(6.0)	7,197	(6.0)	7,246	(6.1)	7,669	(6.4)	7,212	(6.1)	6,560	(5.5)	7,333	(6.2)	8,162	(6.8)
Current, 26 + cig/day	2,275	(1.9)	1,692	(1.4)	1,441	(1.2)	1,464	(1.2)	2,474	(2.1)	1,717	(1.4)	1,328	(1.1)	1,353	(1.1)
Former, quit = 10 years	11,031	(9.3)	11,198	(9.4)	11,691	(9.8)	12,150	(10.2)	10,986	(9.2)	11,026	(9.3)	11,945	(10.0)	12,113	(10.2)
Former, quit 11–20 years	9,728	(8.2)	10,291	(8.6)	10,420	(8.7)	9,516	(8.0)	9,523	(8.0)	10,275	(8.6)	10,595	(8.9)	9,562	(8.0)
Former, quit 20 + years	8,332	(7.0)	10,391	(8.7)	10,896	(9.1)	9,812	(8.2)	6,569	(5.5)	9,827	(8.2)	11,799	(9.9)	11,236	(9.4)

(Continued)

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TABLE 1 (Continued)

Characteristics	Nova group 4 quartiles in %g/d								Nova group 4 quartiles in %kcal/d							
	1st		2nd		3rd		4th		1st		2nd		3rd		4th	
	Mean or *N*	**(SD) (%)**	**Mean or *N***	**(SD) (%)**	**Mean or *N***	**(SD) (%)**	**Mean or *N***	**(SD) (%)**	**Mean or *N***	**(SD) (%)**	**Mean or *N***	**(SD) (%)**	**Mean or *N***	**(SD) (%)**	**Mean or *N***	**(SD) (%)**
Current, pipe/cigar/occas	18,971	(15.9)	12,180	(10.2)	7,155	(6.0)	3,840	(3.2)	19,768	(16.6)	13,430	(11.3)	5,439	(4.6)	3,509	(2.9)
Current/Former, missing	3,342	(2.8)	3,446	(2.9)	3,981	(3.3)	4,685	(3.9)	2,737	(2.3)	3,639	(3.1)	4,048	(3.4)	5,030	(4.2)
Physical Activity [*n* (%)]																
Inactive	29,230	(24.5)	23,508	(19.7)	21,859	(18.3)	19,626	(16.5)	32,060	(26.9)	22,469	(18.9)	19,312	(16.2)	20,382	(17.1)
Moderately inactive	42,406	(35.6)	41,380	(34.7)	39,148	(32.8)	36,326	(30.5)	43,300	(36.3)	41,104	(34.5)	38,288	(32.1)	36,568	(30.7)
Moderately active	29,003	(24.3)	29,926	(25.1)	31,454	(26.4)	36,512	(30.6)	27,652	(23.2)	31,064	(26.1)	32,541	(27.3)	35,638	(29.9)
Active	18,001	(15.1)	22,721	(19.1)	23,502	(19.7)	22,756	(19.1)	15,781	(13.2)	22,017	(18.5)	25,618	(21.5)	23,564	(19.8)
Missing	551	(0.5)	1,657	(1.4)	3,230	(2.7)	3,972	(3.3)	398	(0.3)	2,538	(2.1)	3,434	(2.9)	3,040	(2.6)
Hypertension [*n* (%)]																
No	86,118	(72.3)	76,280	(64.0)	72,812	(61.1)	77,860	(65.3)	93,510	(78.5)	78,960	(66.2)	68,386	(57.4)	72,214	(60.6)
Yes	22,795	(19.1)	21,828	(18.3)	21,352	(17.9)	19,694	(16.5)	23,261	(19.5)	23,716	(19.9)	21,552	(18.1)	17,140	(14.4)
Do not know	10,278	(8.6)	21,084	(17.7)	25,029	(21.0)	21,638	(18.2)	2,420	(2.0)	16,516	(13.9)	29,255	(24.5)	29,838	(25.0)
Hyperlipidaemia [*n* (%)]																
No	81,417	(68.3)	69,363	(58.2)	63,533	(53.3)	55,946	(46.9)	89,347	(75.0)	71,914	(60.3)	58,837	(49.4)	50,161	(42.1)
Yes	20,534	(17.2)	14,916	(12.5)	12,770	(10.7)	10,304	(8.6)	23,474	(19.7)	16,347	(13.7)	11,033	(9.3)	7,670	(6.4)
Do not know	17,240	(14.5)	34,913	(29.3)	42,890	(36.0)	52,942	(44.4)	6,370	(5.3)	30,931	(26.0)	49,323	(41.4)	61,361	(51.5)
Relative Mediterranean diet (51) [*n* (%)]																
Low	18,300	(15)	33,811	(28)	39,834	(33)	43,173	(36)	10,633	(8.9)	36,325	(30.5)	45,808	(38.4)	42,352	(35.5)
Medium	52,658	(44)	56,708	(48)	55,184	(46)	54,614	(46)	51,694	(43.4)	58,211	(48.8)	53,030	(44.5)	56,229	(47.2)
High	48,233	(40)	28,673	(24)	24,175	(20)	21,405	(18)	56,864	(47.7)	24,656	(20.7)	20,355	(17.1)	20,611	(17.3)
FSA-NPS DI Score* (50) [mean (SD)]	5.2	(2.1)	5.9	(1.9)	6.2	(2.0)	6.5	(2.2)	5.1	(2.0)	5.9	(1.9)	6.1	(2.0)	6.7	(2.2)
Energy intake, kcal/d [mean (SD)]	2,030	(611)	2,056	(599)	2,083	(604)	2,116	(650)	2,142	(642)	2,047	(615)	2,028	(595)	2,068	(611)
Alcohol intake, g/d [mean (SD)]	15	(21)	13	(17)	11	(15)	8	(13)	15	(21)	13	(18)	12	(15)	9	(12)
Fiber intake, g/d [mean (SD)]	23	(8)	23	(8)	23	(8)	23	(8)	23	(8)	22	(7)	22	(8)	23	(8)
Total fat intake, g/d [mean (SD)]	77	(27)	80	(29)	81	(30)	82	(31)	82	(28)	79	(29)	79	(29)	81	(30)

(Continued)

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TABLE 1 (Continued)

Characteristics	Nova group 4 quartiles in %g/d								Nova group 4 quartiles in %kcal/d							
	1st		2nd		3rd		4th		1st		2nd		3rd		4th	
	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)	Mean or *N*	(SD) (%)
Carbohydrate intake, g/d [mean (SD)]	216	(74)	224	(70)	232	(71)	246	(80)	231	(80)	226	(73)	226	(70)	236	(74)
Total proteins, g/d [mean (SD)]	90	(29)	87	(27)	86	(26)	84	(26)	95	(30)	86	(28)	84	(25)	83	(25)
Calcium intake, g/d [mean (SD)]	994	(432)	1,023	(406)	1,014	(397)	950	(405)	998	(443)	1,014	(415)	1,007	(396)	962	(387)
Sodium intake, g/d [mean (SD)]	2,649	(1,017)	2,737	(1,063)	2,725	(1,048)	2,719	(1,032)	2,654	(1,035)	2,584	(998)	2,711	(1,031)	2,881	(1,074)

*A higher FSAm-NPS Dietary Index score reflects an overall lower nutritional quality of consumed foods.

of consumed foods, increased with increasing fourth of UPF intake. **Supplementary Tables 6A–C** present the characteristics of the study population by sex-specific quartiles of relative intake for Nova groups 1 to 3. Subjects in the higher quartiles for diets rich in fresh and minimally processed foods (Nova group 1;% kcal/day) had higher Mediterranean diet scores (51) (**Supplementary Table 6A**).

The contribution of UPF intake to overall diet varied substantially within the different countries (**Supplementary Table 5** and **Supplementary Figures 1A,B**). The contribution of UPF intake to overall diet in grams/day varied from 7% (France) to 23% (Norway) and their contribution to overall daily energy intake varied from 16% (Spain and Italy) to 46% (for the Norway).

Supplementary Tables 7A,B present the contributions of the different EPIC food groups to the four Nova categories expressed in g/day and kcal/day using the middle bound scenario. "Tea and coffee" were the highest contributors for Nova group 1 while "Beer and cider" were the main contributors to Nova group 3 and "carbonated/soft/isotonic drinks and diluted syrups" were the highest contributors to Nova group 4 when using the absolute values in g/day. When considering the contributions in kcal/day, "fruits" were the main contributors to Nova group 1, while "Bread, crispbread and rusks" were the main contributors for both Nova groups 3 and 4.

The 3 Nova scenarios (lower bound = lowest degree of processing; middle bound = most likely scenario and upper bound = more processed scenario) performed by the international team (USP and IARC) for the Spanish food list were compared with the coding (most likely scenario) applied in Spain to the Spanish food list as one of the quality controls. This demonstrated good comparability (Spearman correlation for % energy derived from UPF = 0.78) between the codes independently assigned by the two teams for the middle bound/most likely scenario (**Table 2**). The lower and middle bound scenarios gave very similar results while the associations in the upper bound scenario were lower. The weighted kappa statistics also demonstrated good agreement (kappa ranged between 0.48 and 0.68 depending on sex and region) between the two independently assigned Nova classifications for the Spanish EPIC cohort (**Supplementary Table 8**).

Associations were investigated between the consumption of the 4 Nova groups and objective biomarkers related to food processing. Associations of industrial ITFA plasma levels (elaidic acid) with intakes of the different Nova groups in g/day, kcal/day, % of g/day and % of kcal/day were investigated in a subset of subjects from the nested case-control studies embedded in EPIC (N = 9,460) and are presented in **Table 3**. The % of grams and energy derived from UPF (Nova group 4) were fair to moderately and statistically significantly positively correlated with ITFA (elaidic acid) plasma levels

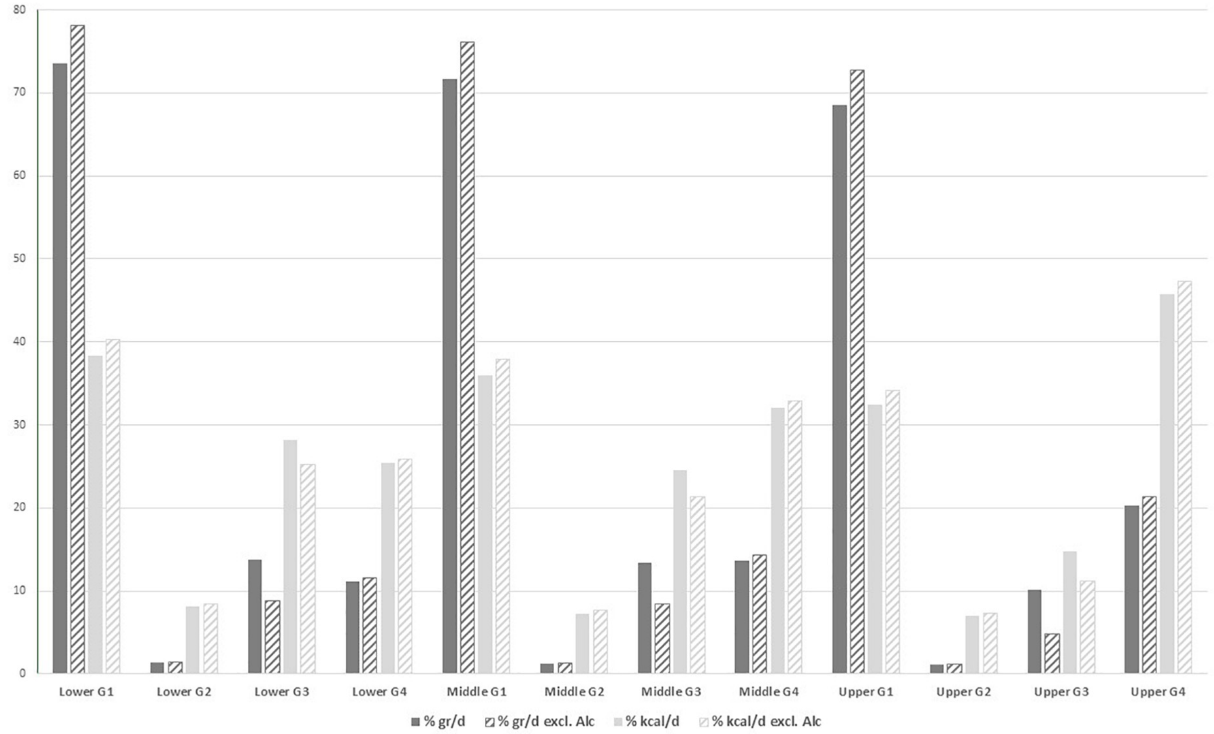

FIGURE 1
Distributions of the different Nova categories, group G1 to G4, using the three different scenarios (lower, middle and upper bound) for the total EPIC cohort (*N* = 476,768; distributions per country are provided as **Supplementary Tables** and **Figures**). Results derived from the Nova classification in which alcoholic drinks were excluded have been shaded in lighter color font.

(Spearman *r* for middle bound scenario = 0.37 and 0.54, respectively), while inverse or lower positive correlations were found with any other Nova group (see **Table 3**). Nova group 1 (fresh and minimally processed foods) also showed a positive association when considering % grams/day (Spearman *r* for middle bound scenario = 0.17) but an inverse association when considering % kcal/day (Spearman *r* for middle bound scenario =−0.07). Overall, the correlations of the middle bound scenario (the most likely scenario) were most in line with our hypotheses that higher intakes of UPF would lead to higher plasma ITFA levels compared to the lower and upper bound scenario; this suggests better performance of this most likely scenario.

Associations of urinary methyl syringol sulfate with intakes of the different Nova groups (in g/day, kcal/day, % of g/day and % of kcal/day) were similarly investigated in another subset of subjects, derived from the EPIC calibration study (*N* = 417) and are presented in **Table 4**. These results also demonstrated fair correlations between the UPF (Nova 4) group and this food processing metabolite while inverse associations for Nova groups 1 and 2 and null for Nova group 3 (except for the Nova group 1 values expressed in grams/day). Associations were again strongest for the middle bound scenario and when using the % kcal/day units.

Sensitivity analyses were run for the Nova groups (the three different scenarios and expressed as g/day, kcal/day, % of g/day and % of kcal/day) using partial correlations adjusted for sex, age and BMI which gave very similar results as for the unadjusted analyses, while additionally adjusting for country attenuated the correlations (see **Supplementary Tables 9**, **10**).

Discussion

The results from this multicenter European study, demonstrate sociodemographic and geographical differences in the consumption of UPF. Furthermore, the comparison with the objective biomarkers, i.e., plasma ITFA and a urinary methylsyringol metabolite showed fair to moderate correlations with the % energy derived from UPF further supporting that the Nova classification is generally suitable for the evaluation of food according to the degree of processing among European populations. The broad variety of foods included in the UPF (Nova 4) group may partially explain the fair to moderate correlations found in relation to the food processing biomarkers. The higher correlations found when considering energy intakes instead of grams of UPF in relation to the food processing biomarkers may be due

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TABLE 2 Correlations between the % of Energy from Ultra-Processed Food (UPF) obtained from the Nova coding performed by the Spanish team versus those obtained via the coding performed by the international team for the Spanish food list using the three different scenarios: lower bound (LB), middle bound (MB) and upper bound (UB) for classifying Nova group 4 (Ultra-processed foods).

		Spearman correlation			Weighted kappa	SE for Kappa	Lower CI	Upper CI	Weighted kappa	SE for Kappa	Lower CI	Upper CI	Weighted kappa	SE for Kappa	Lower CI	Upper CI
	N	LB	MB	UB	LB				MB				UB			
Total EPIC Spain	41,437	0.77	0.78	0.54	0.58	0.0025	0.57	0.58	0.58	0.0025	0.58	0.59	0.37	0.0025	0.36	0.37
Male	15,629	0.72	0.73	0.45	0.53	0.0040	0.52	0.54	0.53	0.0040	0.53	0.54	0.30	0.0040	0.29	0.31
Female	25,808	0.80	0.80	0.59	0.61	0.0031	0.60	0.61	0.61	0.0031	0.61	0.62	0.40	0.0031	0.40	0.41
Asturias	8,542	0.75	0.75	0.60	0.55	0.0054	0.54	0.56	0.55	0.0054	0.54	0.56	0.42	0.0054	0.41	0.43
Male	3,083	0.71	0.72	0.53	0.51	0.0010	0.51	0.51	0.52	0.0010	0.52	0.52	0.36	0.0010	0.35	0.36
Female	5,459	0.76	0.77	0.64	0.57	0.0013	0.56	0.57	0.57	0.0013	0.56	0.57	0.45	0.0013	0.45	0.45
Granada	7,879	0.84	0.84	0.57	0.65	0.0056	0.64	0.66	0.66	0.0056	0.64	0.67	0.39	0.0056	0.38	0.40
Male	1,796	0.81	0.82	0.51	0.62	0.0007	0.62	0.62	0.62	0.0007	0.62	0.62	0.34	0.0007	0.34	0.34
Female	6,083	0.84	0.85	0.58	0.66	0.0014	0.66	0.66	0.67	0.0014	0.66	0.67	0.40	0.0014	0.40	0.40
Murcia	8,515	0.82	0.83	0.60	0.63	0.0054	0.62	0.64	0.64	0.0054	0.63	0.65	0.41	0.0054	0.40	0.42
Male	2,684	0.78	0.79	0.53	0.59	0.0009	0.59	0.59	0.59	0.0009	0.59	0.60	0.36	0.0009	0.36	0.36
Female	5,831	0.84	0.84	0.63	0.65	0.0013	0.65	0.65	0.65	0.0013	0.65	0.65	0.44	0.0013	0.44	0.44
Navarra	8,084	0.76	0.76	0.53	0.56	0.0056	0.55	0.58	0.57	0.0056	0.56	0.58	0.36	0.0056	0.35	0.37
Male	3,908	0.72	0.72	0.45	0.53	0.0011	0.53	0.53	0.53	0.0011	0.53	0.53	0.30	0.0011	0.30	0.31
Female	4,176	0.77	0.77	0.60	0.58	0.0011	0.58	0.58	0.58	0.0011	0.58	0.58	0.43	0.0011	0.43	0.43
San Sebastian	8,417	0.70	0.71	0.45	0.51	0.0054	0.50	0.52	0.52	0.0054	0.51	0.53	0.30	0.0054	0.28	0.31
Male	4,158	0.66	0.67	0.35	0.47	0.0011	0.47	0.47	0.48	0.0011	0.47	0.48	0.22	0.0011	0.22	0.22
Female	4,259	0.74	0.74	0.55	0.55	0.0011	0.54	0.55	0.55	0.0011	0.55	0.55	0.37	0.0011	0.37	0.37

to the higher energy content of foods high in trans-fat and smoked meat.

The correlation with the food processing biomarkers was slightly higher for the middle bound scenario than for the lower and upper bound scenarios, which suggests better performance of this most likely scenario. Hence, future analyses investigating disease outcomes in relation to the consumption of UPF using the Nova classification are advised to predominantly use the middle bound scenario.

Adjusting the analyses for sex, age and BMI had overall little impact on the correlations with the food processing biomarkers. However, adjustment for country attenuated the correlations (**Supplementary Tables 9**, **10**). These reduced correlations when adjusting for country could potentially be due to loss in power. In addition, the different number of food items in the questionnaires of the various countries (**Supplementary Table 1**) may also contribute to this attenuation when adjusting for country (e.g., FFQs with fewer food items and less details may underestimate transfatty acid intakes).

Characterisation of the degree of food processing in EPIC demonstrated differences between countries, with contributions of UPF intake to the overall diet in grams/day varying from 7% (France) to 23% (Norway) and their contributions to overall energy intake varying from 16% (Spain and Italy) to 46% (the Norway). In addition, differences were also found between sociodemographic groups in the consumption of ultra-processed and minimally processed foods. Indeed, participants in the highest fourth of UPF consumption tended to be younger, taller, more often current smokers, more physically active, have a lower level of attained education, have a higher reported intake of energy and lower reported intake of alcohol. These results on the characterisation of the degree of food processing in EPIC are in line with the findings from the NutriNet-Santé Cohort (apart from the result for physical activity, showing higher consumption of UPF among highly active people in EPIC) (16, 52). However, overall the consumption of UPF in EPIC was lower than in other surveys and cohorts while the consumption of minimally processed foods was overall higher in comparison with recent studies from the UK and France for instance (13, 16, 19, 52, 53) and a comparison across the nineteen countries (53). This difference may potentially be due to the fact that the baseline data in EPIC, used in this study, have been collected in the late 1990s, when dietary patterns in many European countries may still have been predominantly based on fresh food products and, to a lower extent, UPF. It should also be noted that the characteristics investigated in **Table 1** should be interpreted with caution as factors such as age, sex, country, etc. may also play a role in some of these findings (e.g., higher consumers of UPF may potentially be more active because they are younger).

Our study is the largest ongoing multicentre cohort study conducted in Europe with a large battery of detailed participant information. Except for a study investigating associations between UPF consumption and urinary concentrations of phthalates and bisphenol (two biomarkers for exposure to packaging materials) in a nationally representative sample of the US population (54), and two studies investigating metabolic biomarkers of diet quality and UPF in European children (55, 56), according to our knowledge this is the first study that investigates the validity of the Nova classification by comparison with food processing biomarkers in blood and urine. Strengths are the wide range of exposures covered by the 9 different European countries, the use of the standardized methodology and procedures to collect participant information, the use of validated FFQs and standardized methods for classifying food items regarding processing with nutritional experts. Still some limitations need to be acknowledged. Dietary questionnaires provide less detailed information on food processing than data from 24 h recalls or food diaries; though the EPIC questionnaires are very detailed, delivering a food list of more than 11,000 food items after decomposing recipes into ingredients. We acknowledge that differences in dietary questionnaires between the EPIC centres could potentially affect the Nova food processing categories. However, a standardized data coding protocol was employed across the EPIC centres, which included disaggregation of homemade recipes into ingredients (commercial recipes were not decomposed into ingredients). This disaggregation into ingredients was essential to correctly assess the consumption of culinary ingredients (Nova group 2); however, this may have led to an overrepresentation of foods classified as Nova group 1 and 2 items instead of group 3 and group 4 items as some of these ingredients may have been processed (e.g., canned) while this level of detail is not available in dietary questionnaires. In addition, recipes that were made at home in the 1990s may nowadays be industrially processed. All the data used in these methodological analyses, namely the dietary intakes as well as the food processing biomarkers were collected at baseline. It should be considered that for some products, the food processing techniques might have changed over time (e.g., recent trans-fat ban in several countries) (57). To consider such potential changes over time in future etiological analyses, three different scenarios were created, namely lower, middle and upper bound scenarios. Although the middle bound scenario compares best with the objective ITFA measurements also taken at baseline, the lower and upper bound scenarios can still be used in sensitivity analyses to explore the potential impact of further industrialisation of food products and of changes in consumer habits to convenience foods over time (considering that the food environment may have changed over time compared to baseline). Still, the lack of dietary follow-up data could be considered as a potential limitation for etiological

TABLE 3 Unadjusted associations of elaidic acid levels in plasma with the daily grams, energy, % grams and % energy intake from the 4 different Nova groups and middle bound scenario (*N* = 9460).

Middle bound	Pearson correlation		Spearman correlation	
	R (Unadjusted association)	*p*-value (unadjusted)	*R* (Unadjusted association)	*p*-value (unadjusted)
Expressed in g/day				
Unprocessed or minimally processed foods –G1	0.20	<0.0001	0.25	<0.0001
Processed culinary ingredients –G2	–0.38	<0.0001	–0.43	<0.0001
Processed foods –G3	–0.35	<0.0001	–0.37	<0.0001
Processed foods –G3 excl. alcohol intake	–0.30	<0.0001	–0.31	<0.0001
Ultra-processed foods –G4	0.37	<0.0001	0.44	<0.0001
Ultra-processed foods –G4 excl. alcohol intake	0.37	<0.0001	0.44	<0.0001
Expressed in kcal/day				
Unprocessed or minimally processed foods –G1	–0.11	<0.0001	–0.10	<0.0001
Processed culinary ingredients –G2	–0.43	<0.0001	–0.48	<0.0001
Processed foods –G3	–0.32	<0.0001	–0.32	<0.0001
Processed foods –G3 excl. alcohol intake	–0.25	<0.0001	–0.26	<0.0001
Ultra-processed foods –G4	0.45	<0.0001	0.47	<0.0001
Ultra-processed foods –G4 excl. alcohol intake	0.45	<0.0001	0.48	<0.0001
Expressed in % of g/day incl. alcohol intake				
Unprocessed or minimally processed foods –G1	0.18	<0.0001	0.17	<0.0001
Processed culinary ingredients –G2	–0.39	<0.0001	–0.46	<0.0001
Processed foods –G3	–0.40	<0.0001	–0.44	<0.0001
Ultra-processed foods –G4	0.30	<0.0001	0.37	<0.0001
Expressed in % of kcal/day incl. alcohol intake				
Unprocessed or minimally processed foods –G1	–0.07	<0.0001	–0.07	<0.0001
Processed culinary ingredients –G2	–0.46	<0.0001	–0.49	<0.0001
Processed foods –G3	–0.34	<0.0001	–0.34	<0.0001
Ultra-processed foods –G4	0.53	<0.0001	0.54	<0.0001
Expressed in % of g/day excl. alcohol intake				
Unprocessed or minimally processed foods –G1	0.08	<0.0001	0.07	<0.0001
Processed culinary ingredients –G2	–0.41	<0.0001	–0.47	<0.0001
Processed foods –G3	–0.35	<0.0001	–0.39	<0.0001
Ultra-processed foods –G4	0.28	<0.0001	0.34	<0.0001
Expressed in % of kcal/day excl. alcohol intake				
Unprocessed or minimally processed foods –G1	–0.11	<0.0001	–0.11	<0.0001
Processed culinary ingredients –G2	–0.47	<0.0001	–0.51	<0.0001
Processed foods –G3	–0.29	<0.0001	–0.29	<0.0001
Ultra-processed foods –G4	0.52	<0.0001	0.53	<0.0001

Supplementary Table 9 presents the correlations for the 4 different Nova groups for lower, middle and upper bound scenarios adjusted for sex, age, BMI and country.

analyses. Finally it should also be noted that the objective biomarkers for food processing conveniently available and used in this study (elaidic acid and a syringol metabolite) are only reflecting part of the industrial processes. Therefore, the use of extra food processing biomarkers is recommended for future analyses when resources for additional measurements (e.g., additives metabolites, furan compounds, pyrrole compounds and pyrazine compounds) are available. It should also be noted that dietary biomarkers are also prone to within person variability (depending on people's recent dietary intakes and the time of specimen collection), while unfortunately only one single biospecimen collection was available for all subjects. In addition, consumption of naturally smoked foods classified as processed foods may also contribute to the measurement of syringol metabolites in addition to the consumption of UPF.

In conclusion, our analyses on the characterisation of the degree of food processing among various participating countries

TABLE 4 Unadjusted associations of urinary methylsyringol sulfate with the daily grams, energy, % grams and % energy intake from the 4 different Nova groups and middle bound scenario (N = 417).

Middle bound	Pearson correlation		Spearman correlation	
	R (Unadjusted association)	*p*-value (unadjusted)	*R* (Unadjusted association)	*p*-value (unadjusted)
Expressed in g/day				
Unprocessed or minimally processed foods –G1	0.16	0.001	0.22	<0.0001
Processed culinary ingredients –G2	−0.20	0.0001	−0.30	<0.0001
Processed foods –G3	0.13	0.007	0.12	0.01
Processed foods –G3 excluding alcohol intake	−0.07	0.14	−0.04	0.44
Ultra-processed foods –G4	0.35	<0.0001	0.40	<0.0001
Ultra-processed foods –G4 excluding alcohol intake	0.35	<0.0001	0.39	<0.0001
Expressed in kcal/day				
Unprocessed or minimally processed foods –G1	−0.24	<0.0001	−0.27	<0.0001
Processed culinary ingredients –G2	−0.30	<0.0001	−0.36	<0.0001
Processed foods –G3	0.06	0.26	0.10	0.03
Processed foods –G3 excluding alcohol intake	0.03	0.55	0.08	0.10
Ultra-processed foods –G4	0.37	<0.0001	0.41	<0.0001
Ultra-processed foods –G4 excluding alcohol intake	0.37	<0.0001	0.40	<0.0001
Expressed in % g/day including alcohol intake				
Unprocessed or minimally processed foods –G1	−0.06	0.23	−0.07	0.18
Processed culinary ingredients –G2	−0.37	<0.0001	−0.41	<0.0001
Processed foods –G3	−0.07	0.172	−0.07	0.15
Ultra-processed foods –G4	0.25	<0.0001	0.29	<0.0001
Expressed in % kcal/day including alcohol intake				
Unprocessed or minimally processed foods –G1	−0.33	<0.0001	−0.37	<0.0001
Processed culinary ingredients –G2	−0.39	<0.0001	−0.42	<0.0001
Processed foods –G3	0.04	0.36	0.07	0.15
Ultra-processed foods –G4	0.41	<0.0001	0.43	<0.0001
Expressed in % g/day excluding alcohol intake				
Unprocessed or minimally processed foods –G1	−0.0003	0.996	−0.02	0.75
Processed culinary ingredients –G2	−0.36	<0.0001	−0.39	<0.0001
Processed foods –G3	−0.26	<0.0001	−0.24	<0.0001
Ultra-processed foods –G4	0.27	<0.0001	0.32	<0.0001
Expressed in % kcal/day excluding alcohol intake				
Unprocessed or minimally processed foods –G1	−0.32	<0.0001	−0.36	<0.0001
Processed culinary ingredients –G2	−0.38	<0.0001	−0.41	<0.0001
Processed foods –G3	0.02	0.70	0.05	0.35
Ultra-processed foods –G4	0.42	<0.0001	0.43	<0.0001

Supplementary Table 10 presents the correlations for the four different Nova groups and the lower, middle and upper bound scenarios adjusted for sex, age, BMI and country.

in the EPIC cohort demonstrated a pronounced gradient between and within countries, with higher consumption of UPF in individuals who were younger, taller, current smokers, more physically active, and with lower level of attained education, higher reported intake of energy and lower reported intake of alcohol. In addition, the comparison with the objective biomarkers, i.e., plasma ITFA and urinary syringol metabolites showed fair to moderate correlations with the % energy derived from UPF, supporting that the Nova classification is generally suitable for the evaluation of UPF among European populations.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: EPIC data and biospecimens are available for investigators who seek to answer important questions on health and disease in the context of research projects that are consistent with the legal and ethical standard practices of IARC/WHO and the EPIC centres. The primary responsibility for accessing the data, including the NOVA categories obtained in the frame of the present publication, belongs to the EPIC centres that provided them. The use of a random sample of anonymised data from the EPIC study can be requested by contacting epic@iarc.fr. The request will then be passed to members of the EPIC Steering Committee for deliberation. Requests to access these datasets should be directed to epic@iarc.fr.

Ethics statement

The studies involving human participants were reviewed and approved by IARC Ethics Committee (IEC). The patients/participants provided their written informed consent to participate in this study.

Author contributions

IH: conceptualization and writing – original draft. IH, CB, CC, and GN: data curation. NK, RW, CB, and CC: formal analysis. IH and CM: funding acquisition. IH, FR, GN, CC, NK, RW, CB, CM, and RL: investigation. MG, CM, and RL: supervision. All authors: writing – review and editing and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1035580/full#supplementary-material

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EDITED BY
Fernanda Rauber,
University of São Paulo, Brazil

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Lauren E. O'Connor,
United States Department of Agriculture (USDA), United States
Carolina Donat,
Instituto de Salud Global de Barcelona (ISGlobal), Spain

*CORRESPONDENCE
Camila Corvalán
ccorvalan@inta.uchile.cl

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Impact of the use of food ingredients and additives on the estimation of ultra-processed foods and beverages

Camila Zancheta Ricardo[1], Ana Clara Duran[2,3], Mariana Fagundes Grilo[2], Natalia Rebolledo[4], Ximena Díaz-Torrente[5], Marcela Reyes[4] and Camila Corvalán[4]*

[1]Doctoral Program in Public Health, School of Public Health, University of Chile, Santiago, Chile, [2]Center for Food Studies and Research, University of Campinas, Campinas, Brazil, [3]Center for Epidemiological Studies in Nutrition and Health, University of São Paulo, São Paulo, Brazil, [4]Institute of Nutrition and Food Technology, University of Chile, Santiago, Chile, [5]Doctoral Program in Nutrition and Food, University of Chile, Santiago, Chile

Introduction: Increasing consumption of ultra-processed foods (UPF), defined by the NOVA classification, has been associated with obesity and other health outcomes. However, some authors have criticized the UPF definition because it is somewhat subjective. Most studies identify UPF using food descriptions; nevertheless, NOVA developers described a list of ingredients, including substances not commonly used for cooking and "cosmetic additives" that could be used to identify UPF. Assessing the impact of the use of different UPF definitions is particularly relevant with respect to children's diet, because several dietary policies target this age group. Thus, our study compared the frequency of UPF among foods and beverages and their share in the diet of Chilean preschoolers using three different methods of identifying UPF.

Methods: We used cross-sectional 24-h dietary recall data from 962 preschoolers enrolled in the Food and Environment Chilean Cohort (FECHIC) in 2016. All foods and beverages consumed were classified according to NOVA, considering their description (classic method), the presence of ingredients markers of UPF (ingredient marker method), and the presence of markers plus all cosmetic additives (food additive method). We also estimated the caloric share and quintiles of UPF consumption using the three methods. We used kappa coefficients, consistency-of-agreement intra-class correlation (CA-ICC), absolute agreement intra-class correlation (AA-ICC), and weighted kappa coefficients for assessing agreement between methods.

Results: The proportion of UPF products were 65% in the "classic," 67% in the "ingredient marker," and 73% in the "food additive" method, and kappa coefficients between methods varied from 0.79 to 0. 91. The caloric share of UPF was 47, 52, and 58% with "classic," "ingredient marker," and "food additive" methods, respectively.

Consistency-of-agreement was higher than the absolute agreement between the methods (CA-ICC = 0.81; AA-ICC = 0.74). For quintiles of UPF consumption, we found weighted kappa of 0.65 as measure of agreement between "classic" and "ingredient marker," and 0.51 between "classic" and "food additive" methods.

Conclusion: Searching for all possible markers of UPF in the list of ingredients increased the proportion of food products identified as UPF compared to the classic method. These differences affected the estimated caloric share of UPF in Chilean preschoolers' diets.

KEYWORDS

children, NOVA classification, food additives, ultra-processed food, food processing, child diet, Chile

1. Introduction

The growing prevalence of obesity and non-communicable diseases worldwide is associated with changes in the food system, the weakening of traditional eating patterns, and the increasing participation of packaged and ready-to-eat products in the diet (1). Several classification systems considering food processing have been proposed, with the NOVA food classification system being the most extensively used (2). NOVA classifies all food and beverages into four groups: minimally processed foods (MPF), processed culinary ingredients (PCI), processed foods (PF), and ultra-processed foods (UPF) (3).

Nutritional epidemiologists are increasingly using the NOVA classification system (1), which has already been applied to food purchase data (4), in national food consumption surveys (5–8), cohort studies (9–11), and a randomized controlled trial (12). Furthermore, several systematic reviews show that higher UPF consumption is associated with obesity and non-communicable diseases, especially in adults (13–15). The concept of UPF also appears in the nutrition profile model proposed by the Pan American Health Organization (16) and various dietary guidelines (17–20), which recommend diminishing or avoiding the consumption of these products.

NOVA aims to classify foods and beverages considering the extent and purpose of industrial processing, and its first versions were mainly based on the description of food categories that compose each group (21, 22). According to this definition UPF are generally ready-to-eat industrial formulations made from various food-derived ingredients, many exclusively used by the food industry, combined with food additives through various industrial processes. However, some foods such as breads or cheeses can be considered processed or UPF so NOVA classification has been criticized because the UPF definition is considered somewhat arbitrary (23, 24). For those cases, NOVA developers proposed a method to identify a UPF using the list of ingredients. They stated that it is possible to identify a UPF by the presence of food substances never or rarely used in traditional recipes or by the presence of functional classes of additives used to make a product palatable or more appealing—which they defined as "cosmetic additives" (3).

The extensive use of ingredients to support the application of NOVA should result in a more objective classification, potentially reducing misclassification. Assessing the impact of the use of different UPF definitions is particularly relevant with respect to children's diet, because they are high UPF consumers (5, 8, 25, 26), and several dietary policies are targeted to this age group (27, 28). Thus, in the current study, we took advantage of detailed data on food composition and dietary intake from a cohort of Chilean preschoolers to compare the use of three different methods to identify UPF ("classic," "ingredient marker," and "food additives"). To our knowledge, no published work has made such comparisons.

2. Materials and methods

2.1. Design and subjects

We conducted a secondary cross-sectional analysis using baseline data from the Food Environment Chilean Cohort (FECHIC), a cohort study initiated in 2016 with 962 3-6-year old low-to-middle income preschoolers from Southeast Santiago, Chile, to assess changes in dietary intake after the Chilean Law of Food Labeling and Advertising (27). We included all children with dietary data available for 2016 (n = 958) for the current analyses. Details on recruitment and inclusion criteria are available elsewhere (29).

2.2. Ethics

The ethics committees of the Institute of Nutrition and Food Technology (INTA) and the School of Public Health, University of Chile, approved this study. Mothers signed the informed consent on behalf of their children.

2.3. Dietary intake

Trained dietitians collected 24-h dietary recalls following the United States Department of Agriculture (USDA) Automated Multiple-Pass method (30). They entered data on portion size, type of preparation, type of food, and product brand and flavor in the case of packaged foods, besides the source of the food and eating location, directly in SER-24, a software developed by the Center for Research in Food Environments and Prevention of Nutrition-Associated Diseases (CIAPEC), INTA (29, 31). A photographic food atlas was used to estimate the portion size consumed accurately (29). The primary caretaker was responsible for reporting the diet, and the children complemented the information for the occasions when the respondent was absent (e.g., school time).

2.4. NOVA food classification system

Briefly, NOVA considers the extent and purpose of industrial processing and classifies each food and beverage into one of four exclusive groups: Group 1. Minimally processed foods (MPF) are defined as whole foods or parts of foods not modified or that have undergone only processes aimed at facilitating preservation, storage, or consumption. In general, there is no inclusion of new ingredients. MPF includes grains, vegetables, milk, meats, eggs, seeds, and nuts; Group 2. Processed culinary ingredients (PCI) are substances extracted or collected in nature and primarily used in food preparation, such as salt, sugar, butter, oils, and vinegar; Group 3. Processed foods (PF) are combinations of minimally processed foods with culinary ingredients. PF includes salted meats, fish and canned vegetables, fruit compotes, and artisanal types of bread and cheese; Group 4. Ultra-processed foods (UPF) are generally ready-to-eat industrial formulations made from various food-derived ingredients, many exclusively used by the food industry, combined with food additives through various industrial processes. Examples of UPF are industrialized sodas, confectionaries, chocolates, ice cream, hamburgers, sausages, and other reconstituted meat products, pizzas and other frozen dishes, instant soups, cookies, cakes, and different types of packaged bread, among others (3).

We used different methods to identify UFP based on the NOVA food classification system.

2.4.1. Classic method to identify UPF using NOVA classification system

We identified all unique foods and beverages consumed by children reported in the 24-h dietary recalls (n = 1,861) and categorized each of them according to the degree of processing in one of the four mutually exclusive groups defined by the NOVA classification. The developers of NOVA have previously described this NOVA classification method for large data sets (32–34). In the classic method, each food and beverage was classified considering the following information: group and type of food, packaged or unpackaged, and brand and flavor, when available. Simple preparations included in the software SER-24 (e.g., cooked rice or fried egg) were classified based on their main component. We disaggregated more elaborate homemade recipes into their components, and each of them was individually classified. Unbranded traditional Chilean bread was classified as PF and industrially produced, packaged, branded bread as UPF. Ready-to-eat meals such as pizza, hamburgers, and hotdogs purchased in supermarkets or fast-food chains were considered UPF.

The food classification process was carried out by a postgraduate dietitian at CIAPEC and reviewed by a second dietitian. Disagreements (0.4%) were discussed and resolved by consensus. A third rater classified a random subset of 5% of SER-24 records to verify the agreement between evaluators. We found an agreement of 97.4% and a kappa coefficient of 0.95, indicating almost perfect agreement between raters for the classic method of NOVA classification.

2.4.2. Ingredient marker method to identify UPF using NOVA classification system

In this method, the lists of ingredients of 1,449 packaged foods (98.8% of all consumed packaged foods) were used by linking SER-24 records with information from food labels collected in supermarkets in Santiago in 2015 and 2016 [details of data collection are published elsewhere (35)]. The database linking procedure was performed manually by trained research assistants using the descriptive information available in the dietary data (36). We considered a product as UPF when it declared at least one ingredient not commonly used in home cooking or at least one class of additive that could modify its sensorial characteristics (or a "cosmetic additive"), according to NOVA developers (3). Monteiro et al. (3) presented a list of ingredients that would be exclusively used in UPF, including different sources of sugars, carbohydrates, proteins, and fats (i.e., non-additive markers of UPF); classes of food additives; and some specific names of these additives that consumers could commonly recognize. Based on this recommendation and the examples displayed in their publication, we searched the lists of ingredients for the following terms (in Spanish): inverted sugar, dextrose, fructose, lactose, glucose, maltodextrin, concentrated juice, syrup, protein concentrated, protein isolate, whey protein, soy protein,

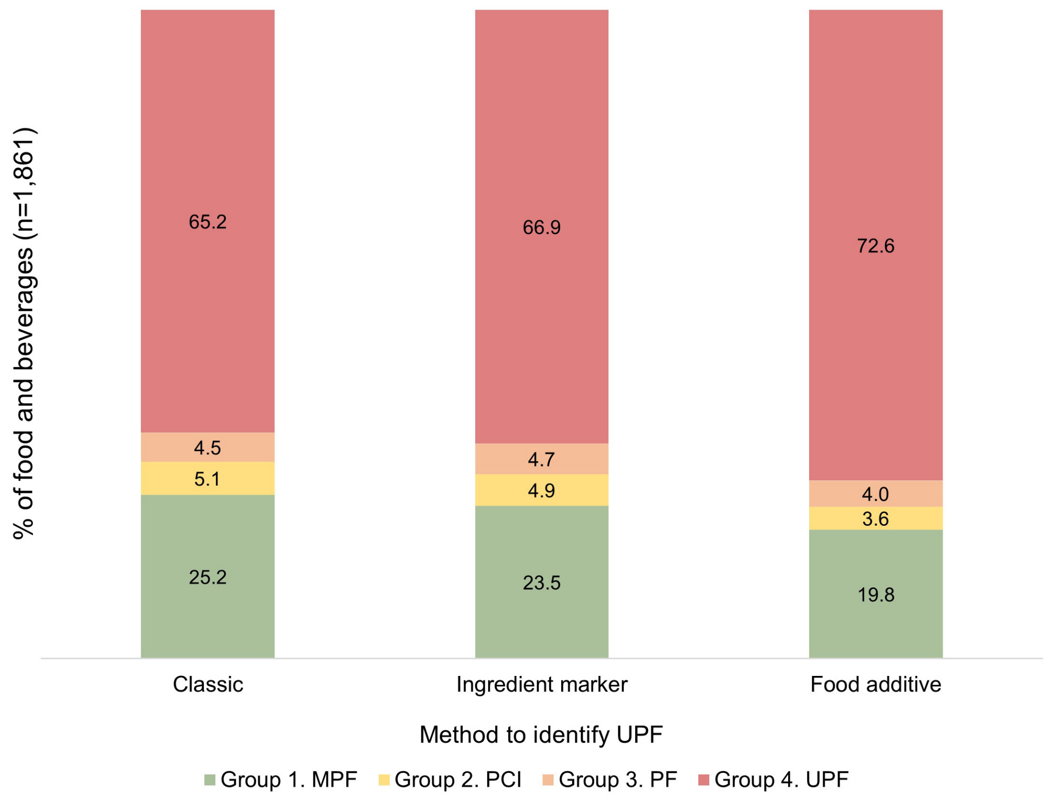

FIGURE 1
Proportion (%) of NOVA food groups using three methods to identify UPF in foods and beverages (*n* = 1,861). MPF, minimally processed foods; PCI, processed culinary ingredients; PF, processed foods; UPF, ultra-processed foods. In "classic method," UPF was identified by using food description; in "ingredient marker method," by searching for substances not commonly used in traditional recipes and names of functional classes of cosmetic additives in the lists of ingredients; and in "food additive method" by searching for UPF ingredient markers, names of functional classes and all individual names of cosmetic additives.

wheat gluten, casein, fiber, maltitol, sorbitol, interesterified, hydrogenated or fractionated oil/fat, gelatin, pectin, gums, mechanically separated meat, milk whey, dairy product solids, modified starch, monosodium glutamate, artificial essence/flavor, sucralose, aspartame, acesulfame, cyclamate, saccharin, Stevia, flavoring, flavor enhancer, color, emulsifier, emulsifying salt, sweetener, thickener, and antifoaming, bulking, carbonating, foaming, gelling and glazing agents. Packaged products that did not include these ingredients were reviewed and classified into the remaining NOVA food groups based on their description (our classic method) (*n* = 322).

We did not have access to the list of 412 foods and beverages (22.1% of total products), which remained in the NOVA group defined by the classic method. Most of them were minimally processed foods that do not have a list of ingredients such as fruit, vegetables, meats, eggs, grains, water, and herbs for tea (63.4%). We also did not obtain information on ingredients for unpackaged bakery products (13.8%), some processed meat and cheeses (7.8%), prepared foods and desserts from fast food chains (5.6%), and products provided by the Chilean Ministry of Health or the school meal program (3.4%).

2.4.3. Food additive method to classify foods and beverages using NOVA classification system

The third method to identify UPF was also applied to the packaged products that had a list of ingredients (*n* = 1,449). Besides all ingredient markers of UPF previously described,

TABLE 1 Agreement (%) and kappa coefficient between NOVA food groups obtained using three methods to identify UPF in foods and beverages (*n* = 1,861).

Method	Classic	Ingredient marker	Food additive
Classic	100; 1		
Ingredient marker	95.5; 0.91	100; 1	
Food additive	90.0; 0.79	94.3; 0.88	100; 1

In "classic method," UPF was identified by using food description; in "ingredient marker method," by searching for substances not commonly used in traditional recipes and names of functional classes of "cosmetic" additives in the lists of ingredients; and in "food additive method" by searching for UPF ingredient markers, names of functional classes and all individual names of cosmetic additives. In bold, the perfect agreement and kappa coefficient between a method and itself.

TABLE 2 Distribution (*n*; %) of NOVA food groups obtained in "classic method" according to "ingredient marker" and "food additive" methods in foods and beverages (*n* = 1,861).

Methods	Ingredient marker				Food additive			
Classic	Group 1. MPF	Group 2. PCI	Group 3. PF	Group 4. UPF	Group 1. MPF	Group 2. PCI	Group 3. PF	Group 4. UPF
Group 1. MPF (*n* = 469)	430 (91.7)	0 (0.0)	1 (0.2)	38 (8.1)	360 (77.2)	0 (0.0)	1 (0.2)	106 (22.6)
Group 2. PCI (*n* = 95)	0 (0.0)	90 (94.7)	1 (1.1)	4 (4.2)	0 (0.0)	65 (68.4)	1 (1.1)	29 (30.5)
Group 3. PF (*n* = 84)	0 (0.0)	0 (0.0)	69 (82.1)	15 (17.9)	0 (0.0)	0 (0.0)	57 (67.9)	27 (32.1)
Group 4. UPF (*n* = 1,213)	7 (0.6)	1 (0.1)	16 (1.3)	1.189 (98.0)	6 (0.5)	1 (0.1)	16 (1.3)	1.190 (98.1)

MPF, minimally processed foods; PCI, processed culinary ingredients; PF, processed foods; UPF, ultra-processed foods. In "classic method," UPF was identified by using food description; in "ingredient marker method," by searching for substances not commonly used in traditional recipes and names of functional classes of "cosmetic" additives in the lists of ingredients; and in "food additive method" by searching for UPF ingredient markers, names of functional classes and all individual names of "cosmetic" additives. In bold, the combination of same NOVA group in different methods.

we included additives' specific names in this method. Using the list of ingredients of each product, we searched for all 388 additives defined by Codex Alimentarius (37). In addition to the standardized names, we included in the search terms synonyms described in the Chilean Food Sanitary Regulation (38) and other synonyms, mistyping, and codes of the International Numbering System (INS) found in the dataset. We considered a food additive as cosmetic if it could assume any of the 12 functional classes described by Monteiro et al. (3): flavor enhancer, color, emulsifier, emulsifying salt, sweetener, thickener, and antifoaming, bulking, carbonating, foaming, gelling and glazing agents; or if it was a flavoring (not specified as a functional class in Codex). For example, in this method we searched the lists of ingredients for the term that describes a functional class (e.g., emulsifier) and also for all 122 specific additives that can assume this function (e.g., lecithin, acetic and fatty acid esters of glycerol, agar, carrageenan, propylene glycol, among others). We applied the same method for other classes of cosmetic additives. Products that did not contain those additives remained in the NOVA group previously defined by the "ingredient marker method."

2.5. Food composition table and food categories

We used an updated food composition table created with the nutrition facts panel for the packaged foods consumed by the children as described elsewhere (36). For unpackaged foods, we maintained the nutritional information available at the SER-24 (39).

Each food and beverage were categorized following the approach of previous studies that applied NOVA (26, 33, 40), considering some required adjustments. Final food categories were: (1) water, tea, and coffee; (2) soft drinks; (3) milk and plain yogurt; (4) milk-based drinks; (5) flavored or sweetened yogurt; (6) dairy desserts; (7) cheese; (8) cereals, flours, and pulses; (9) breakfast cereals and granola bars; (10) fresh breads; (11) packaged breads; (12) crackers and cookies; (13) cakes and pies; (14) snacks; (15) confectionaries; (16) fast food; (17) soups, sauces, and salts; (18) meat, fish and eggs; (19) salted, smoked or canned meat or fish; (20) reconstituted meat or fish; (21) fruits and vegetables; (22) fruits and vegetable preserves; (23) baby food; (24) sweeteners; (25) fats and oils. **Supplementary Table 1** presents the description of each food category.

2.6. Statistical analysis

For food and beverages identified on dietary recalls, we calculated the proportion of NOVA groups by dividing the number of foods and beverages in each group by the total number of unique products in the database. We used kappa coefficients to assess the agreement between the different methods of NOVA classification. We considered the following thresholds for kappa values: less than 0.20, between 0.21 and 0.40, between 0.41 and 0.60, between 0.61 and 0.80, and above 0.81 as slight, fair, moderate, substantial, and almost perfect, respectively (41). We also described differences in the proportion of UPF identified using each method by food categories.

As a sensitivity analysis, we verified the agreement between methods in food and beverages only considering the packaged products with a list of ingredients (*n* = 1,449) since the unpackaged products were kept in the same NOVA food groups defined using the food description.

For children's consumption, we estimated the caloric share of UPF (UPF kcal/total kcal) in the diet for each participant and the overall mean caloric share using each classification method. We also predicted the probability density of caloric

TABLE 3 Proportion (%) of UPF in food and beverages using three methods to identify them, according to food categories (n = 1,861).

Food categories	Classic	Ingredient marker	Food additive
Water, tea, and coffee (n = 46)	6.5	8.7	13.0
Sweetened beverages (n = 186)	98.4	99.5	99.5
Milk and plain yogurt (n = 53)	3.8	49.1	60.4
Milk-based drinks (n = 62)	100.0	100.0	100.0
Flavored or sweetened yogurt (n = 89)	100.0	100.0	100.0
Dairy desserts (n = 63)	98.4	96.8	96.8
Cheese (n = 36)	5.6	33.3	66.7
Cereals, flours, and pulses (n = 111)	7.2	6.3	62.2
Breakfast cereals, and granola bars (n = 73)	97.3	95.9	95.9
Fresh breads (n = 8)	0.0	0.0	0.0
Packaged breads (n = 35)	100.0	100.0	100.0
Crackers and cookies (n = 108)	100.0	98.1	98.1
Cakes and pies (n = 75)	100.0	100.0	100.0
Snacks (n = 51)	80.4	60.8	60.8
Confectionaries (n = 188)	100.0	98.4	98.4
Fast food (n = 16)	93.8	93.8	93.8
Soups, sauces, and salts (n = 85)	78.8	81.2	92.9
Meat, fish and eggs (n = 103)	1.0	1.0	1.0
Salted, smoked or canned meat or fish (n = 39)	59.0	61.5	61.5
Reconstituted meat or fish (n = 92)	98.9	100.0	100.0
Fruits and vegetables (n = 155)	0.6	0.6	0.6
Fruits and vegetable preserves (n = 53)	60.4	77.4	77.4
Baby food (n = 11)	54.5	54.5	54.5
Sweeteners (n = 36)	58.3	58.3	61.1
Fats and oils (n = 87)	31.0	32.2	47.1
Total (n = 1,861)	65.2	67.0	72.6

share of UPF for each method with kernel density estimation. Additionally, we ranked UPF consumption into quintiles, with the lowest consumers in the first quintile and the highest consumers in the fifth. Agreement between the caloric share of UPF obtained by the three methods was estimated using a two-way mixed effects model, estimating absolute-agreement intra-class correlation (AA-ICC) and consistency-of-agreement (CA-ICC) (42). We considered the following thresholds for ICC values: less than 0.5, between 0.51 and 0.75, between 0.76 and 0.90, and greater than 0.91 as poor, moderate, good, and excellent agreement, respectively (42). We used linear weighted kappa to assess the agreement between quintiles of UPF consumption (43).

We used the software R to search food additives and Stata v.16.1 for data analysis.

3. Results

We identified 1,861 unique foods and beverages consumed by FECHIC children in 2016. The proportions of UPF varied with the different methods applied, especially when using food additives names. With the "classic method," we classified 65.2% of foods as UPF, but this proportion increased when using more detailed ingredient information, reaching 66.9% with the "ingredient marker method" and 72.6% with the "food additive method" (**Figure 1**). From the former group of UPF, 30.7% had only cosmetic additives, being the most common emulsifiers (78.3%), thickeners (74.2%), flavorings (71.9%), and colors (60.3%) (data not shown).

Despite differences in the proportion of UPF, the agreement between the "classic" and "ingredient marker" methods, and the "ingredient marker" and "food additive" methods was almost perfect (k = 0.91 and k = 0.88, respectively), while the "classic" and "food additive" methods presented substantial agreement (k = 0.79) (**Table 1**). Sensitivity analyses conducted only including packaged foods produced similar agreement rates (**Supplementary Tables 2–4**).

In **Table 2** we explore the discrepancies among methods. Comparing the "classic" and "ingredient marker" methods, we observed that most of the differences were due to foods previously classified as MPF and then as UPF (8.1% of classic MPF; n = 38) and foods classified as PF and then as UPF (17.9% of classic PF; n = 15). Conversely, when using the "food additive" method we observed changes involving all NOVA groups: 22.6% of classic MPF (n = 106), 30.5% of classic PCI (n = 29), and 32.1% of classic PF (n = 27) were classified as UPF when we used all possible cosmetic food additives in the classification.

Table 3 describes the proportion of UPF using different classification methods by food categories. In milk and plain yogurt, cheese, and cereals, flours, and pulses, we observed that more than half of the food products would change from non-UPF to UPF when using ingredients or additive markers. In

TABLE 4 Caloric share (%; 95% confidence interval) of NOVA food groups in preschoolers' diet using three methods to identify UPF.

Method	Group 1. MPF	Group 2. PCI	Group 3. PF	Group 4. UPF
Classic	34.2 (33.2–35.2)	7.9 (7.5–8.2)	10.5 (9.9–11.1)	47.4 (46.2–48.6)
Ingredient marker	29.4 (28.5–30.3)	7.7 (7.3–8.0)	10.9 (10.2–11.5)	52.0 (50.9–53.2)
Food additive	23.7 (22.8–24.5)	7.2 (6.9–7.6)	10.7 (10.1–11.3)	58.4 (57.3–59.5)

Food Environment Chilean Cohort (FECHIC) (n = 958). MPF, minimally processed foods; PCI, processed culinary ingredients; PF, processed foods; UPF, ultra-processed foods. In "classic method," UPF was identified by using food description; in "ingredient marker method," by searching for substances not commonly used in traditional recipes and names of functional classes of "cosmetic" additives in the lists of ingredients; and in "food additive method" by searching for UPF ingredient markers, names of functional classes and all individual names of "cosmetic" additives.

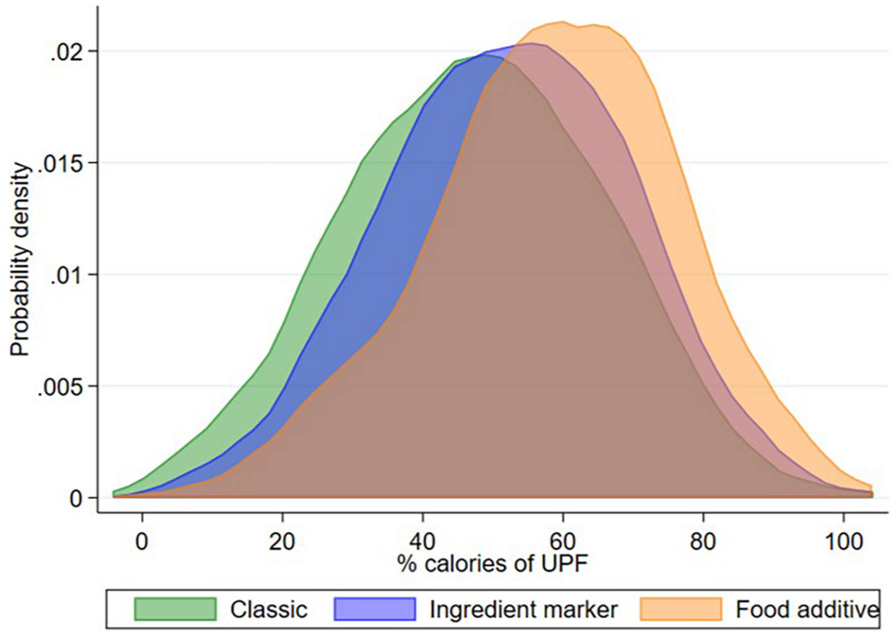

FIGURE 2
Probability density of caloric share of UPF in preschoolers' diet using three methods to identify UPF. Food Environment Chilean Cohort (FECHIC) (n = 958). In "classic method," UPF was identified by using food description; in "ingredient marker method," by searching for substances not commonly used in traditional recipes and names of functional classes of "cosmetic" additives in the lists of ingredients; and in "food additive method" by searching for UPF ingredient markers, names of functional classes and all individual names of "cosmetic" additives.

snacks, fruits and vegetables preserves, and fats and oils, the proportion of UPF varied by about 20% depending on the UPF method used (Table 3). To provide an idea of the relative importance of each of these food categories in the study sample, we present the mean energy intake of FECHIC children by food category in Supplementary Table 5.

We also observed differences in the caloric share of UPF in children's diets when using the three methods to identify UPF. The caloric share of UPF was 47.4, 52.0, and 58.4% when using the "classic," "ingredient marker," and "food additive" methods, respectively (Table 4). Figure 2 shows a right displacement of the caloric share of UPF when we used either ingredients or additives to identify UPF. The density curves obtained for the "classic" and "ingredient marker" methods were similar in their symmetry and kurtosis; for the "food additive method," the density curve was sharper and more left-tailed than the others.

Despite the differences in the caloric share observed between the three methods, overall AA-ICC was 0.74 (95% CI0.56–0.84) and CA-ICC was 0.81 (95% CI 0.80–0.83), indicating moderate to good and good consistency. Measures of agreement were higher for the comparison between "classic" and "ingredient marker" method (AA-ICC: 0.80 [95% CI 0.71–0.86]; CA-ICC: 0.83 [95% CI 0.81–0.85]) than between classic and additive-bases method (AA-ICC: 0.62 [95% CI 0.20–0.80]; CA-ICC: 0.73 [95% CI 0.70–0.76]).

When comparing quintiles of the dietary share of UPF by classification method, we found a higher proportion of agreement in the fifth and first quintiles for both comparisons: 71.7 and 65.1% for "classic" and "ingredient marker," and 60.7% and 54.7% for "classic" and "food additive" method (Table 5). We observed substantial (weighted kappa = 0.65) and moderate agreement (weighted kappa = 0.51) between "classic" and

TABLE 5 Distribution (*n*; %) of quintiles of the caloric share of ultra-processed foods (% of total calories) in preschoolers' diet according to different methods to identify UPF.

Classic method	Ingredient marker method*				
	Q1 (<37.1%)	Q2 (37.1–47.5%)	Q3 (47.6–57.1%)	Q4 (57.2–67.4%)	Q5 (>67.5%)
Q1 (<30.7%)	125 (65.1)	38 (19.8)	15 (7.8)	8 (4.2)	6 (3.1)
Q2 (30.7–42.4%)	59 (30.7)	87 (45.3)	22 (11.5)	16 (8.3)	8 (4.2)
Q3 (42.5–52.1%)	6 (3.1)	58 (30.4)	94 (49.2)	18 (9.4)	15 (7.9)
Q4 (52.2–64.0%)	1 (0.5)	8 (4.2)	53 (27.6)	105 (54.7)	25 (13)
Q5 (> 64.1%)	1 (0.5)	1 (0.5)	7 (3.7)	45 (23.6)	137 (71.7)
Classic method	**Food additive method****				
	Q1 (<43.8%)	Q2 (43.9–54.4%)	Q3 (54.5–64.0%)	Q4 (64.1–73.4%)	Q5 (>73.5%)
Q1 (<30.7%)	105 (54.7)	48 (25)	23 (11.9)	9 (4.7)	7 (3.7)
Q2 (30.7–42.4%)	68 (35.4)	56 (29.2)	33 (17.2)	25 (13)	10 (5.2)
Q3 (42.5–52.1%)	14 (7.3)	69 (36.1)	50 (26.2)	39 (20.4)	19 (10)
Q4 (52.2–64.0%)	4 (2.1)	17 (8.9)	77 (40.1)	55 (28.6)	39 (20.3)
Q5 (>64.1%)	1 (0.5)	2 (1.1)	8 (4.2)	64 (33.5)	116 (60.7)

Food Environment Chilean Cohort (FECHIC) (n = 958).
*Agreement = 86.1%; Weighted kappa = 0.65.
**Agreement = 80.3%; Weighted kappa = 0.51.
In "classic method," UPF was identified by using food description; in "ingredient marker method," by searching for substances not commonly used in traditional recipes and names of functional classes of "cosmetic" additives in the lists of ingredients; and in "food additive method" by searching for UPF ingredient markers, names of functional classes and all individual names of "cosmetic" additives.

"ingredient marker" and "classic" and "food additive" methods, respectively.

4. Discussion

Our results indicate that using ingredient information for applying NOVA food classification system increased the proportion of food and beverages classified as UPF. However, despite the observed differences, we found almost perfect agreement between the "classic" and "ingredient marker" methods, and substantial agreement between "classic" and "food additive" methods in classifying food products. When applied to dietary data of Chilean preschoolers, we observed that the mean caloric share of UPF increased by 5% when we included information from ingredient markers and 11% when we included food additives compared to estimates based on food description (i.e., classic method). However, we found good consistency and absolute agreement for the caloric share of UPF among the three methods. The agreements for UPF quintiles were substantial and moderate for "classic" vs. "ingredient marker" and "classic" vs. "food additive" methods, respectively.

To our knowledge, this is the first study that reports how different UPF assessment methods shift the proportion of UPF in food products and dietary share. Previous studies have compared the consistency of the NOVA classification system between different raters. In a study conducted in the United States, two Ph.D. level researchers used the food item description to apply NOVA and two other food processing classifications on the 100 foods most consumed by children who participated in the National Health and Nutrition Examination Survey 2013–2014 (44). The authors found a lower agreement with NOVA than with the other classifications. In France, in an online survey, more than 100 specialists in food and nutrition classified two lists of foods into NOVA groups, and the consistency among evaluators both for a list of generic foods and for marketed foods with lists of ingredients was low (Fleiss' kappa coefficient around 0.3) (24). Conversely, in our study, we performed inter-rater reliability using food description to apply NOVA (our classic method) in 5% of all products of SER-24 (n = 306) and found almost perfect agreement. This finding suggests that trained raters might have a better classification consistency.

In our study, most differences between the "classic" and "ingredient marker" methods were due to foods that were classified as MPF or PF in the classic method and then as UPF when we searched for ingredient markers. Exploring the lists of ingredients, we found that fruit preserves with and without added sugars were classified as UPF in the "ingredient marker method" because they had concentrated juice, coloring, or thickener. Many fluids and powdered milk previously classified as MPF included emulsifiers. Other discrepancies were found in cheeses with coloring or gelatin. We also found a small number of foods classified as UPF in the "classic method" and then as PF (about 1% of products). Some condensed milk, for instance, was classified as UPF when we applied the "classic method," but as PF with the use of the "list of ingredients method" because they were only made of milk and sugar. Among snacks, reported differences were because some potato chips were only made of potato, oil, salt, and antioxidants, and classified as PF by the "ingredient marker" method. Including food additive names in the search resulted in about a quarter of foods from the other "classic" NOVA categories (MPF, PCI, and PF) to the UPF group. For cereals, most of the disagreement was due to the food additive riboflavin found in pasta. Riboflavin is a vitamin that can also be used as coloring (37). For fats and oils, the difference was explained by the presence of polydimethylsiloxane, an additive that could be an emulsifier, antifoaming, or anticaking agent (37). In salts, we found silicon dioxide, an additive that could be antifoaming, anticaking, or a carrier agent (37).

Applying the NOVA classification based on the list of ingredients could be a more objective procedure to identify a UPF. When the NOVA developers proposed a list of markers of UPF, they were attempting to solve an issue in the differentiation of processed and ultra-processed foods in some categories in which it is possible to find both types of processing as bakery products (3). However, in our study, extensively searching for possible cosmetic additives in the list of ingredients resulted in the identification of products that do not represent the concept of UPF. Our results showed that a third of the packaged products (30.6%) were classified as UPF only by the presence of a cosmetic additive in the "food additive" method (i.e., these products did not present a non-additive marker of UPF), including some milk, cheese, cereals, and oils. These products are usually classified as minimally processed, culinary ingredients, or processed foods because they contain whole foods and ingredients that we usually use in our kitchens.

Our findings suggest that the extensive use of food additives seems to result in an excessive proportion of products classified as UPF. This scenario was probably due to the large variety of functional classes of additives indicated as cosmetics by NOVA's proposing authors (12 of 27 classes of Codex Alimentarius) and because many food additives could have different uses. Additionally, the extensive list of approved food additives makes their use for food classification difficult since they are not always declared with the exact name and code available in Codex. Finally, our experience indicates that using food additives could not be done routinely for researchers and policymakers interested in applying the NOVA food classification system. Searching for all food additives was time-consuming and code intensive. Then, to identify ultra-processed foods and inform consumers (i.e., using a warning label) (45, 46) or for other types of regulatory policies, it is necessary a clearer definition of UPF, with fewer but more consistent markers, that could potentially vary by food category. To specify these markers, it is also relevant consider that "cosmetic additives" is not a definition stated in the Codex Alimentarius, what could be a barrier to their use in regulations.

On the other hand the three methods applied were highly consistent in the identification of UPF in food categories such as soft drinks, breads, cookies, cakes and pies, milk-based drinks, and confectionaries, which represent a substantial part of UPF consumption in different countries (25, 33, 47). Overall, we identified 69.3% of UPF searching only for non-additive marker and about 99.9% using non-additive markers plus sweeteners, colors, and flavorings (data not shown). However, even using a few functional classes of additives to identify UPF should be considered with caution, because some vitamins and minerals used for fortification can also be considered cosmetic additives. This is the case of riboflavin, calcium carbonate and carotenes—all classified as colors according to the Codex Alimentarius (37). Flavorings also deserve to be dealt with caution. Despite being commonly used in foods (48), they are not a functional class of additives described by the Codex Alimentarius (37). Most classic UPF without a non-additive marker (i.e., requiring the presence of a food additive to be identified) were soft drinks, milk-based beverages, and confectionaries (data not shown). These products are commonly cited as examples of UPF and could be classified as UPF when the list of ingredients are not available (3).

The differences in the identification of UPF affected the estimated caloric share of UPF in the FECHIC preschoolers. The extension of disagreements is at least partly explained by the importance of specific food categories in the energy intake of our participants. Most disagreements in the frequency of UPF were found in milk and plain yogurt and cereals, flours, and pulses, and these categories also contributed to most of the energy intake of our sample (**Supplementary Table 5**). Besides the differences observed between the three methods, we found moderate to good agreement between them by analyzing children's diets. Particularly, we found good consistency of agreement, which indicates that the values were systematically correlated (42). Because there is no recommendation on tolerable or adequate consumption levels of UPF, authors usually compare quartiles or quintiles of the dietary share of UPF in the population's diets to study associations between UPF consumption and health outcomes (1, 49). Using quintiles of dietary share of UPF of Chilean preschoolers, we found better agreements in the first and fifth quintiles. Thus, our findings suggest that the use of lists of ingredients and food additives for applying NOVA food classification could impact greater the description of the consumption of UPF than epidemiological studies in which associations are reported comparing the fifth and the first quintile. However, further analyses would be relevant to assess the exact impact of misclassification, particularly in populations where the consumption of dairy products or cereals are important UPF sources.

This study has some limitations. We could not consider the specific use of the food additive for each product as this information was not always available in the package. Instead, we decided to consider all functional classes an additive could assume. Then, an additive was defined as cosmetic if listed by the Codex Alimentarius in any of the twelve classes indicated by Monteiro et al. (3). Further, different products available in the food supply but not consumed by our participants were not included in our study, and our results may not be generalizable to high-income children or adults. On the other hand, our study has several strengths. We used detailed dietary data, which included the brand and flavor of industrialized foods and beverages. This information helped us apply the "classic method" to identify UPF and allowed us to match food items with a database containing ingredient information. We linked most foods and beverages with updated package information collected in supermarket chains with the largest sales volumes in Santiago in the same year of dietary food collection. We also searched for more than 350 food additives described by the Codex Alimentarius and included multiple synonyms described in the Chilean regulation or found in the packaged products database.

In conclusion, searching for all possible markers of UPF in the list of ingredients increased the proportion of UPF in food products, particularly in some food categories; and those differences affected the overall caloric share of UPF in the Chilean preschoolers' diet. The current definition of UPF considers terms that are not stated in international and widely used food regulatory documents such as the Codex Alimentarius (e.g., "cosmetic additive"), nor have clear definitions such as substances with no or unusual use in home cooking. These limitations make the classification of UPF more prone to be disputed when they are an essential part of regulatory or legal processes. Taking into consideration a clearer range of other attributes of UPF besides their ingredients can contribute to a more unbiased definition of UPF for food policies.

Data availability statement

The data used in this article are available upon reasonable request directed to CC, ccorvalan@inta.uchile.cl.

Ethics statement

This study was reviewed and approved by the Ethics Committees of Institute of Nutrition and Food Technology (INTA) and the School of Public Health, University of Chile. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

CZR: conceptualization, methodology, formal analysis, writing—original draft, and writing—review and editing. AD: methodology and writing—review and editing. MG: writing—review and editing. NR and XD-T: writing—review and editing. MR: funding acquisition. CC: conceptualization, methodology, writing—review and editing, and funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.1046463/full#supplementary-material

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EDITED BY
Gustavo Cediel,
University of Antioquia, Colombia

REVIEWED BY
Chella Perumal Palanisamy,
Qilu University of Technology, China
Luiz Menezes-Junior,
Universidade Federal de Ouro Preto, Brazil
Bruna Barbosa,
Universidade Federal de Ouro Preto, Brazil
Mariana Vidigal,
Universidade Federal de Ouro Preto, Brazil

*CORRESPONDENCE
Karem Lays Soares Lopes
karemresidencia@gmail.com
Flávia Campos Corgosinho
flaviacorgosinho@ufg.br

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The degree of food processing can influence serum fatty acid and lipid profiles in women with severe obesity

Karem Lays Soares Lopes[1]*, Nayra Figueiredo[2], Fabiana Martins Kattah[1], Glaucia Carielo Lima[1], Emilly Santos Oliveira[1], Maria Aderuza Horst[1], Lila Missae Oyama[3], Ana Raimunda Dâmaso[4], Renata Guimarães Moreira Whitton[5], Valéria de Souza Abreu[6], Amélia Cristina Stival Duarte[1], Gustavo Duarte Pimentel[1,2] and Flávia Campos Corgosinho[1,2]*

[1]Post-Graduation Program in Nutrition and Health, Faculty of Nutrition, Federal University of Goiás – PPGNUT-FANUT-UFG, Goiânia, Goiás, Brazil, [2]Post-Graduation Program in Health Sciences, Faculty of Medicine, Federal University of Goiás, Goiânia, Goiás, Brazil, [3]Nutrition Physiology Laboratory, Federal University of São Paulo, São Paulo, Brazil, [4]Post-Graduation Program in Nutrition, Paulista Medicine School, Federal University of São Paulo, São Paulo, Brazil, [5]Department of Physiology, Institute of Biosciences, University of São Paulo, São Paulo, Brazil, [6]Alberto Hassi Hospital, Goiânia, Goias, Brazil

Background: The increase in the prevalence of obesity is associated with the increase in the consumption of ultra-processed foods and may be related to the increase in the disorders involving metabolism and the transport and storage of fatty acids.

Objective: To evaluate the effect of processed food consumption according to the degree of processing on the serum fatty acid levels and lipid profile of women with severe obesity.

Methods: This was a cross-sectional study. Data were collected from anthropometric assessments, the food frequency questionnaire (FFQ), and blood tests for lipidogram studies and serum fatty acid measurements. The foods consumed were identified through the FFQ and classified according to the degree of processing based on the NOVA rating, and the frequencies of consumption were transformed into scores, as proposed by Fornés methodology. Data were analyzed using IBM SPSS Statistics, version 21. The significance level for the analysis was set at 5%.

Results: This study included 44 women with a mean age of 40.59 years and mean body mass index of 48.61 kg/m^2. An inverse association was observed between the consumption of unprocessed and the occurrence of hypertriglyceridemia ($p = 0.021$) and levels of triglycerides ($p = 0.047$), total cholesterol ($p = 0.030$), and very low-density lipoprotein-cholesterol ($p = 0.039$). The consumption of processed foods was positively associated with the presence of hypertriglyceridemia ($p = 0.044$) and omega 6/3 ratio ($p = 0.001$) and negatively associated with total omega 3 levels ($p = 0.011$). The consumption of processed foods was positively associated with total cholesterol ($p = 0.041$) and negatively associated with the omega 3/6 ratio ($p = 0.001$). A negative correlation was found between the average consumption of ultra-processed foods (at least once a week) and serum level of high-density lipoprotein ($p = 0.035$).

Conclusion: The consumption of processed and ultra-processed foods was associated with unfavorable lipid profiles and fatty acid levels in women with severe obesity. These results emphasize the importance of promoting the consumption of unprocessed food to mitigate metabolic disorders linked to processed food intake.

KEYWORDS

nova food classification, ultra-processed foods, food, processed, obesity, lipoproteins, fatty acids, omega-3

1. Introduction

Obesity is a chronic multifactorial disease characterized by an increase in adipose tissue, which generates chronic low-grade inflammation and poses health risks (1, 2). The increasing prevalence of obesity is a global public health problem. In 2020, 988 million people in the world presented obesity and it is estimated that in 2035 there will be an increase to 1,914 million representing 24% of the population (3). The prevalence of severe obesity (BMI > 40 kg/m^2) has also been increasing in recent years and is more prevalent among women (4). Excess body weight is the sixth risk factor for the development and aggravation of many diseases, including chronic non-communicable diseases (NCDs) (5, 6). Individuals with obesity tend to have insulin resistance, which increases lipolysis and decreases lipogenesis. The increased efflux of fatty free acids (FFA) promotes ectopic fat accumulation, increases reactive oxygen species (ROS), induces apoptosis of pancreatic cells, and inhibits the insulin receptor (IRS-1) (7, 8). Furthermore, central adiposity is associated with increased concentrations of cytokines that activate inflammatory pathways. Such mechanisms increase the risk of developing cardiovascular diseases (9–11).

Over the period 2000 to 2016, the absolute global amount of all cardiovascular diseases increased over time, having as main risk factors high blood pressure, diabetes, smoking, and unhealthy diet. Food consumption is closely connected to weight gain, mainly as a modifiable factor (12, 13). Studies have shown that, in many cases, the sources of calories in the diet can be a stronger determinant of weight gain and comorbidities than calorie quantity (14). Thus, dietary composition is a determinant of the incidence and prevalence of obesity (14).

Modern lifestyle is characterized by a decrease in the consumption of unprocessed/minimally processed foods, dietary sources of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), which have cardioprotective and anti-inflammatory activity. However, PUFAs need to be consumed in adequate proportions, omega 6 fatty acids in excess modulate pro-inflammatory activity (15–19). In the other hand, it has been observed an increase in the consumption of processed and ultra-processed foods, which have high caloric density and contain many sugars, sodium, saturated, and trans fats (20).

Although the association between fatty acids and metabolic disturbances is being studied extensively, there is a lack of studies on the association between the degree of food processing and levels of serum fatty acids and lipid profile, especially in women with severe obesity (21–27). Thus, the present study evaluated the association between the consumption of processed food according to the extent and purpose of processing and serum fatty acids and lipids in women with severe obesity.

2. Methods

2.1. Location and type of study

This was a cross-sectional and convenience study involving patients with severe obesity (BMI > 40 kg/m^2) from a public hospital in Goiânia, GO. This study was approved by the Research Ethics Committee of the Federal University of Goiás (Number 3.251.178) and the Ethical Committee of Research of the Dr. Alberto Rassi State Hospital (HGG) (Number 3.392.511). All the volunteers signed a written informed consent form before participating in the study.

2.2. Participants

The initial sample of this study was 49 participants. After an exclusion of volunteers who presented incomplete data ($n = 3$); outliers ($n = 2$), the sample became 44 volunteers aged between 20 and 59 years with severe obesity (BMI > 40 kg/m^2) waiting for bariatric surgery at a public hospital in Goiânia were enrolled in this study. The exclusion criteria were presence of acute inflammatory diseases, infectious or neoplastic diseases, or genetic syndrome; alcohol consumption of >30 g/day; chronic use of supplements (vitamin D and omega 3) in the last 6 months; and use of drugs that cause elimination of fat via feces. All exclusion criteria were self-reported. Recruitment and data collection took place during the first consultation with the surgeon prior to any nutrition consultation and intervention (Figure 1). All our patients were recruited at the same moment, at the first appointment of the surgeon and the data was collected all at once, at the first dietitian appointment, before any dietetic guidance. Moreover, all the participants were asked if they lost weight in the last month and the majority did not change their weight previously of the data collect.

2.3. Data collect

Anamnesis (name, age, presence of comorbidities, medications) data were collected. Data from anthropometric assessments and blood examination were recorded, and a food frequency questionnaire (FFQ) was also applied.

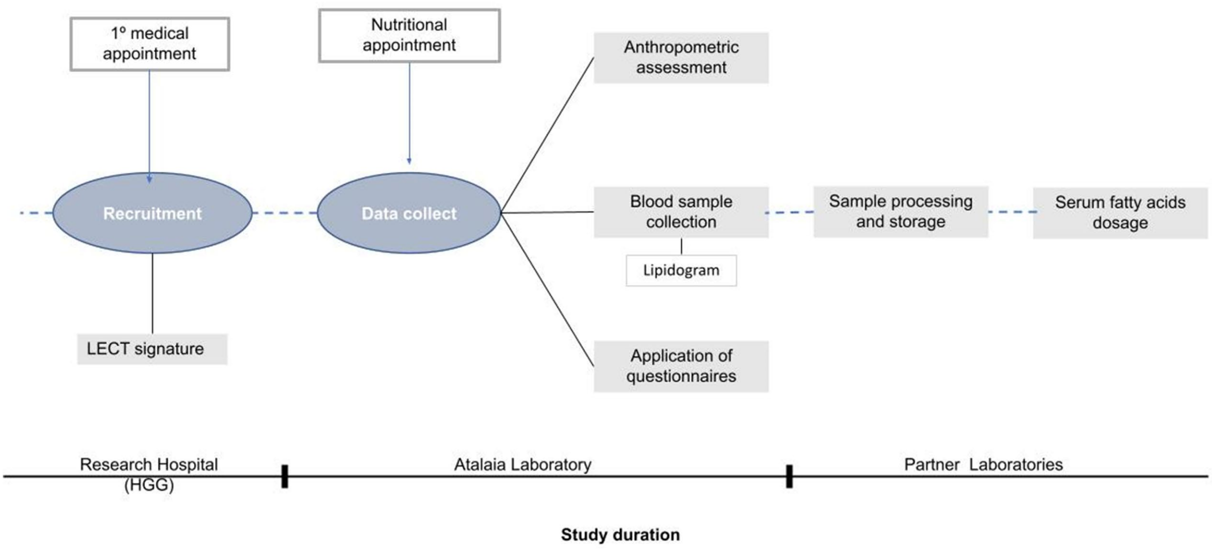

FIGURE 1
Study design: stages of participant recruitment and data collection.

TABLE 1 Food consumption frequencies calculated according to Fornés et al. (2002) (37).

Consumption frequency	Corresponding Score
3 or more times a day	1
2 or 3 times a day	1
1 time a day	1
5 or 6 times a week	0.7856
2 or 4 times a week	0.4284
1 time a week	0.1428
1 to 3 times a month	0.0657
Never or almost never	0

2.3.1. Anthropometric assessment

The measurements of weight, height, waist circumference (WC), hip circumference (HC), and neck circumference (NC) were recorded. All measurements were performed with the participants in light clothes and without shoes, and weight was measured using a weighing balance (Lider, place of manufacture), with a capacity of 200 kg (28). Height was measured using an inextensible metric, and the volunteers were asked to stand in an upright position. The body mass index (BMI) was calculated by dividing the weight by height squared. Circumferences were evaluated using an inelastic measuring tape (29) WC was measured at the level of the umbilical line while the volunteer was standing. The HC was measured at the largest circumference of the hip region (30). The NC was measured just below the level of the thyroid cartilage (31). NC and WC were evaluated and classified on cardiovascular risk and classified in low and high cardiovascular risk (≥34 and ≥88 centimeters respectively) (32, 33).

2.3.2. FFQ and anamnesis

To collect information regarding the usual diet of volunteers, it used the reduced and qualitative version of the FFQ ELSA-Brasil (2013) which includes 95 foods (34). The FFQ data were tabulated in Microsoft Excel 365, and the foods listed in the questionnaire were categorized according to the degree of processing (Supplementary Chart 1), using the guidelines presented in the Food Guide for the Brazilian Population (2014), based on the NOVA rating (35, 36). Each FFQ food was classified into one of the following three groups: unprocessed/minimally processed foods, processed foods, and ultra-processed foods. The categories of culinary ingredients were not included in this study because the FFQ does not cover such items. For statistical analysis, the food consumption frequencies from the FFQ were transformed into numerical values, namely consumption scores, according to the recommendations of Fornés et al. (37). The following formula was used:

$$S_n = (1/365)\left[(a+b)\right]/2$$

where a and b indicate the number of days that each consumption frequency represents in the period of 1 year. For example, the consumption frequency of one-to-three times a month, a would be equal to 12 (considering the consumption of once a month in a period of 12 months) and b would be equal to 36 (considering the consumption of three times a month over a period of 12 months). For consumption frequencies of one or more times per day, the score was considered to be equal to 1 (37). The FFQ scores identified for each frequency of consumption are shown in Table 1.

Subsequently, for statistical analysis, it was considered the average consumption of scores of each degree of processing. The average consumption score is related to the average frequency of consumption, referring to the number of days of the year for each degree of processing.

2.3.3. Blood sample exam

For blood collection, the volunteers were instructed to fast for at least 8 h but not more than 12 h. The collection was performed by trained and qualified professionals through a peripheral puncture of a vein in the forearm.

A lipidogram examination was conducted to determine the levels of triglycerides (TGs), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-c), high-density lipoprotein cholesterol (HDL-c), and very low-density lipoprotein cholesterol (VLDL-c). Biochemical analysis was performed using the colorimetric enzymatic method, specific to each parameter. Of note, the presence of different dyslipidemias was confirmed using the values of TGs, LDL-c and HDL-c, according to the laboratory classification of dyslipidemias in the Updated Brazilian Guidelines on Dyslipidemias and Prevention of Atherosclerosis (38). In addition, an aliquot of blood from each collected sample was centrifuged to separate the serum from the whole blood sample and stored in a freezer at −80°C until further testing for fatty acids.

2.3.4. Extraction and determination of serum fatty acids

The fatty acid profile was determined after extracting the fatty acids from the serum samples; then, the fatty acid patterns of the samples were determined using gas chromatography. The reading and identification of the patterns of acids present in the samples were performed using chromatograms by comparison with known retention times established. The program used in the last step was Compass Chromatography Data System (Compass CDS), version 3.0.2. After the analysis results all the fatty acids from the omega-3 and omega-6 series were summed for the calculation of the ratios omega-3/omega-6 and omega-6/omega-3, an anti-inflammatory and pro-inflammatory index, respectively (17–19). All the analyses regarding the fatty acids were conducted in partnership with the Nutrition Physiology Laboratory of the Federal University of São Paulo and the University of São Paulo (39, 40).

2.3.5. Statistical analysis

Statistical analysis was performed using the IBM SPSS Statistics program, version 21. The normality of the variables and residuals were evaluated using the Shapiro–Wilk test. For the analysis of the association of the different degrees of food processing was used the Generalized Linear Model test (GLzM) in exponential Family considering a normal probability of distribution (Gaussian) and a link function of identity. To investigate the association between food consumption and variables related to lipid profile (triglycerides, total cholesterol, HDL-c, LDL-c, and VLDL-c) and serum fatty acid, we performed a model of linear regression. The lipid profile was adjusted by age and BMI (main effects), since both are established influencing factors of this parameter. We also performed linear regression to investigate the association between food consumption and serum fatty acids. The homoscedasticity was tested by Levene's test. Finally, the sample loss analysis was calculated (Supplementary Table S1).

3. Results

3.1. Sample description

A total of 44 women with an average age of 40.59 years and BMI of 48.61 kg/m^2 were included in this study. The sample loss analysis did not show statistical difference. With regard to circumference measurements, 100% of the women had an increased risk of developing cardiovascular diseases according to the WC, and of developing metabolic disorders according to the NC (Table 2).

Regarding food consumption (Table 2), it was found that the average score for consumption of unprocessed was 0.23, indicating consumption between one and four times a week; the average scores for consumption of processed and ultra-processed foods were 0.18 and 0.10, respectively, indicating that the volunteers consumed them at least once a week. Regarding the presence of dyslipidemia, 72.7% of the volunteers had some type of alteration in the lipid profile, with the most prevalent being a reduction in HDL-c level (81.25%).

Considering the fatty acids, twenty-two were identified and included in the study. Of these, five were saturated fatty acids (SFAs), five were monounsaturated fatty acids (MUFAs), and 12 were polyunsaturated fatty acids (PUFAs) (Table 3). Furthermore, SFA showed the highest occurrence in the sample, with an of 40.72%, followed by PUFA, with 36.05%, and MUFA showed the lowest occurrence, with an average of 23.22%. The average of omega 3 and 6 fatty acids were 6.95 and 29.10%, respectively. The omega 3/6 ratio, which is an indicator of anti-inflammatory activity, had an average of 0.25%. On the other hand, the mean % of omega 6/3 ratio, a pro-inflammatory marker, was 5.16%. The fatty acid profiles are presented in Table 3.

TABLE 2 Descriptive statistics of the lipid profile and other variables.

Variables	Mean		SD*
Age (years)	40.59	±	8.76
Weight (kg)	122.84	±	18.15
Height (m)	1.59	±	0.06
BMI (kg/m^2)**	48.61	±	6.88
WC (cm)***	131.22	±	12.61
HC (cm)	145.64	±	13.76
NC (cm)	41.82	±	3.13
Triglycerides (mg/dL)	141.55	±	57.29
Total Cholesterol (mg/dL)	177.66	±	31.76
HDL-c (mg/dL)	47.43	±	10.39
LDL-c (mg/dL)	105.61	±	28.21
VLDL-c (mg/dL)	24.75	±	7.20
Average consumption score of unprocessed	0.23	±	0.06
Average consumption score of processed foods	0.18	±	0.08
Average consumption score of ultra-processed foods	0.10	±	0.06

SD*, standard deviation; BMI, body mass index; WC, waist circumference (<80 cm); HC, hip circumference; NC, neck circumference (≤34 cm); triglycerides (<150 mg/dL); TC, total cholesterol (<190 mg/dL); HDL-c, high-density lipoprotein (>40 mg/dL); LDL-c, low-density lipoprotein (<130 mg/dL); VLDL-c, very-low-density lipoprotein.

TABLE 3 Descriptive statistics of serum fatty acid data.

Variables	Mean		SD*
Total saturated fatty acids (% area)	40.72	±	2.74
C14:0 (% area)	6.21	±	2.75
C16:0 (% area)	20.76	±	4.20
C18:0 (% area)	12.74	±	1.91
C20:0 (% area)	0.80	±	0.29
C22:0 (% area)	0.21	±	0.19
Total monounsaturated fatty acids (% area)	23.22	±	2.11
C14:1C (% area)	4.61	±	1.96
C16:1n7 (% area)	1.31	±	0.50
C18:1n9 (% area)	14.78	±	3.55
C18:1n7 (% area)	1.48	±	0.34
C20:1n9 (% area)	1.05	±	0.43
Total polyunsaturated fatty acids (%area)	36.05	±	3.89
C18:2n6 (% area)	19.07	±	5.35
C18:3n6 (% area)	4.86	±	1.76
C20:2n6 (% area)	2.45	±	1.04
C20:3n6 (% area)	0.36	±	1.19
C20:4n6 (% area)	0.65	±	1.27
C22:2n6 (% area)	1.71	±	0.90
Omega 6 total (% area)	29.10	±	3.96
C18:3n3 (% area)	3.93	±	2.08
C18:4n3 (% area)	0.72	±	0.36
C20:3n3 (% area)	1.07	±	0.96
C20:4n3 (% area)	0.40	±	0.19
C20:5n3 (% area)	0.11	±	0.42
C22:6n3 (% area)	0.71	±	0.60
Omega 3 total (% area)	6.95	±	3.12
Omega 3/6 ratio	0.25	±	0.14
Omega 6/3 ratio	5.16	±	2.46

SD*, standard deviation; C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid; C20:0, arachidic acid; C22:0, behenic acid; C:16:1n7, palmitoleic acid; C:18:1n7, vaccenic acid; C:20:1n9, cetoleic acid; C18:2n6, linoleic acid; C18:3n6, gamma-linolenic acid; C18:3n6, gamma linolenic acid; C20:2n6, eicosadienoic acid; C:20:3n6, dihomo-gamma-linolenic acid; C20:4n6, arachidonic acid; C22:2n6:13,16, docosadienoic acid; 18:3n3, alpha-linoleic acid; C18:4n3, stearidonic acid; C20:3n3, dihomo-alpha-linolenic acid; C20:4n3, eicosatetraenoic acid; C20:5n3, eicosapentaenoic acid (EPA); C22:6n3, docosahexaenoic acid (DHA).

3.2. Food consumption according to the degree of processing and the lipid profile

A negative correlation was observed between the variables average consumption score of ultra-processed foods and HDL-c level ($p = 0.035$). For the other variables, correlation coefficients were not significant. Regarding the relationship between the lipid profile and degree of food processing, it was found that the average consumption of unprocessed was negatively associated with the levels of TGs ($p = 0.047$; $\beta = -0.371$), TC ($p = 0.030$; $\beta = -0.223$), and VLDL-c ($p = 0.039$; $\beta = -0.049$), under the effect of age (Table 4).

On the other hand, the average consumption of processed foods was positively associated with serum TC levels, and this association was modified by advancing age ($p = 0.041$; $\beta = 1.815$). In addition, the average consumption of unprocessed was negatively associated ($p = 0.021$; $\beta = -0.083$) and the average consumption of processed foods was positively associated ($p = 0.044$; $\beta = 0.335$) with the presence of hypertriglyceridemia, with the interaction of age.

3.3. Food consumption according to the degree of processing and the profile of serum fatty acids

The mean consumption of processed foods was negatively associated with serum levels of total omega 3 ($p = 0.008$; $\beta = -12.64$). In the analysis of the ratios of PUFA families, we found a negative association between the average consumption of processed foods and the omega 3/6 ratio ($p = 0.001$; $\beta = -1.094$) and a positive association between the average consumption of processed foods and omega 6/3 ratio ($p = 0.001$; $\beta = 18.751$) (Table 5). No significant results were observed for the Total SFA, Total PUFA and Total MUFA variables.

4. Discussion

The unquestionable role of diet both in the onset of obesity and in the development of related diseases, such as cardiovascular disease, makes it essential to thoroughly investigate food consumption and its metabolic effects in individuals who present obesity. The classification of foods according to the degree of processing has been used worldwide as an attempt to promote healthy eating and curb the growth of NCDs (41). In this sense, the present study proves to be important for the construction of knowledge about the theme of severe obesity and food intake, according to their processing levels, and fatty acids. To our knowledge, this study is the first to observe a potentially deleterious association between the consumption of processed and ultra-processed foods and levels of serum PUFAs in women with severe obesity.

The present study demonstrated an important association between processed food consumption and omega-3 fatty acids and the pro-inflammatory n6/n3 ratio. Supporting this finding, (42) observed that individuals who consumed a healthy diet (rich in whole grains, fatty fish, and "berries") showed an increase in omega 3 series PUFAs and decline in the amounts of omega 6 and 7 fatty acids, when compared to the control group that consumed a diet rich in refined flours and sugar, with limited consumption of fish and no berries. In addition, the control group showed a reduction in the total concentration of serum omega 3 and an apparent reduction in the total concentration of circulating PUFAs from the beginning to the end of the intervention (43).

The present findings could be partially explained by the food sources of omega 3 and 6. Omega 3 PUFAs are commonly found in unprocessed foods, with little or no occurrence in processed and ultra-processed foods (43). Series 6 PUFAs are abundant in oils of vegetable origin, which are frequent components of industrially produced or processed foods. In addition, the consumption of unprocessed/

TABLE 4 Associations between food consumption according to degree of processing and lipid profile, adjusted by age and BMI.

Dependent variable	*B*	*p*-value	95% CI
Triglycerides			
Score_Total_Intake_Unprocessed	4.413	0.747	(−22.347–31.173)
Score_Total_Intake_Processed	8.088	0.954	(−268.698–284.875)
Score_Total_Intake_Ultraprocessed	−5.974	0.918	(−119.961–108.013)
Score_Total_Intake_Unprocessed * Age	−0.371	**0.047**	(−0.737–−0.004)
Score_Total_Intake_Unprocessed * BMI	0.275	0.206	(−0.151–0.701)
Score_Total_Intake_Processed * Age	1.972	0.221	(−1.188–5.132)
Score_Total_Intake_Processed * BMI	−1.348	0.558	(−5.858–3.163)
Score_Total_Intake_Ultraprocessed * Age	0.719	0.270	(−0.559–1.996)
Score_Total_Intake_Ultraprocessed * BMI	−0.503	0.609	(−2.430–1.425)
Total Cholesterol			
Score_Total_Intake_Unprocessed	10.301	0.170	(−4.405–25.007)
Score_Total_Intake_Processed	−52.822	0.496	(−204.932–99.287)
Score_Total_Intake_Ultraprocessed	−41.567	0.193	(−104.209–21.075)
Score_Total_Intake_Unprocessed * Age	−0.223	**0.030**	(−0.424–−0.021)
Score_Total_Intake_Unprocessed * BMI	−0.027	0.821	(−0.261–0.207)
Score_Total_Intake_Processed * Age	1.815	0.041	(0.078–3.551)
Score_Total_Intake_Processed * BMI	−0.496	0.695	(−2.975–1.982)
Score_Total_Intake_Ultraprocessed * Age	0.468	0.191	(−0.234–1.170)
Score_Total_Intake_Ultraprocessed * BMI	0.414	0.444	(−0.645–1.473)
Very-low-density lipoprotein			
Score_Total_Intake_Unprocessed	0.626	0.720	(−2.791–4.043)
Score_Total_Intake_Processed	−0.367	0.984	(−35.709–34.975
Score_Total_Intake_Ultraprocessed	−2.059	0.782	(−16.614–12.495)
Score_Total_Intake_Unprocessed * Age	−0.049	**0.039**	(−0.096–−0.002)
Score_Total_Intake_Unprocessed * BMI	0.032	0.250	(−0.022–0.086)
Score_Total_Intake_Processed * Age	0.296	0.150	(−0.107–0.699)
Score_Total_Intake_Processed * BMI	−0.188	0.522	(−0.764–0.388)
Score_Total_Intake_Ultraprocessed * Age	0.096	0.248	(−0.067–0.259)
Score_Total_Intake_Ultraprocessed * BMI	−0.041	0.741	(−0.288–0.205)

BMI, body mass index. Model of linear regression.

minimally processed, processed, and ultra-processed foods can have different effects on endogenous metabolism and may alter the metabolism of fatty acids in the body in different ways. Therefore, the consumption of unprocessed/minimally processed and industrialized foods could have influenced the amount of PUFAs found in the serum of the study volunteers (Figure 2).

Considering the roles of these essential fatty acids in the body, inadequate intake can be harmful to health (44). Omega-3 fatty acids are often associated with the reduction of systemic inflammation in overweight individuals because of their action in the production of anti-inflammatory cytokines and against the occurrence of cardiovascular events (45). Thus, the negative association between processed food and serum n-3 PUFAs is an important data, especially considering the studied population, which probably presents an increased systemic pro-inflammatory profile.

Changes in the world food pattern have favored a higher consumption of omega-6 fatty acids, which are mainly present in processed and ultra-processed foods. Omega 6, in higher proportions, can have deleterious effects on health due to its ability to produce bioactive lipids that act as pro-inflammatory agents (46). In the fatty acid biosynthesis pathway, those of the omega 6 series, mainly linoleic fatty acid, are bioconverted through the action of desaturase and elongase enzymes, giving rise to other fatty acids. Among them, arachidonic acid (ARA) stands out, which has a high inflammatory action (47). ARA can be bio converted into bioactive lipids (eicosanoids) called prostaglandins, thromboxanes, leukotrienes, and lipoxins. Eicosanoids increase vasoconstriction, bronchoconstriction, and activate inflammation by increasing the production of reactive oxygen species (ROS), promoting NK cell recruitment, and mediating the production of pro-inflammatory cytokines. Together, exposure to these metabolic changes favors the development of NCDs (48–51).

Studies have shown relevant results pertaining to the proportions of omega-6 and 3 PUFAs, where omega 6/3 ratios of 4–6:1 were associated with reduced cardiovascular risk and inflammatory

TABLE 5 Associations between food consumption according to degree of processing serum fatty acids.

Dependent variable	*B*	*p*-value	95% CI
Total Omega 3			
Score_Total_Intake_ Unprocessed	0.178	0.698	(−0.720–1.076)
Score_Total_Intake_ Processed	−12.644	**0.008**	(−21.932– −3.356)
Score_Total_Intake_ Ultraprocessed	2.018	0.301	(−1.808–5.843)
Omega 3/6 Ratio			
Score_Total_Intake_ Unprocessed	0.021	0.501	(−0.040–0.082)
Score_Total_Intake_ Processed	−1.094	**0.001**	(−1.729–−0.459)
Score_Total_Intake_ Ultraprocessed	0.243	0.068	(−0.018–0.505)
Omega 6/3 Ratio			
Score_Total_Intake_ Unprocessed	−0.205	0.711	(−1.289–0.879)
Score_Total_Intake_ Processed	18.751	**0.001**	(7.536–29.966)
Score_Total_Intake_ Ultraprocessed	−3.877	0.100	(−8.496–0.741)

Model of linear regression.

parameters (44, 52, 53). On the other hand, a high omega 6/3 ratio (20:1) was related to the emergence of dyslipidemia, endothelial dysfunction, and increased inflammation (54). In experimental studies, a low omega 6/3 ratio (4:1) was found to reduce the risk of cardiovascular diseases, by reducing oxidative stress, improving endothelial function, and reducing the occurrence of inflammatory parameters. Hence, the results of the present data are alarming, once it was observed an association between consumption of processed food and omega 6/3 ratio and the mean average of consumption of processed food (once a week) in the present population was above the recommendations.

In contrast, the omega 3/6 ratio seems to have anti-inflammatory and cardiovascular protection activity. A study showed that high omega 3/6 ratio (1:1) was associated with the prevention of obesity and insulin resistance by suppressing TLR-4 (55). Additionally, it was demonstrated that n-3 PUFAs reduce the formation of atherogenic plaques by inhibiting the activation of smooth muscle cells and macrophages and help in the regulation of lipoproteins and TGs, thereby reducing the synthesis of LDL-c and TGs in the liver (56). Hence, the inverse association between ultra-processed food and serum n3/n6 in women with severe obesity highlights the importance of nutritional education actions in order to favor cardiovascular health.

In fact, the present study reinforces the importance of food processing in lipid profile. We have demonstrated that the consumption of ultra-processed food once a week was associated with a worse lipid profile while the consumption of unprocessed food was associated with a lower prevalence of hypertriglyceridemia and best lipid profile in women with severe obesity. In a study performed with adults (men and women) with hypertension, Ferreira et al. (2019) found a positive correlation between the consumption of processed foods and high TC levels (56). In line with these results, Tavares et al. (2012) and Steele et al. (2019) observed a strong correlation between the consumption of ultra-processed foods and the occurrence of

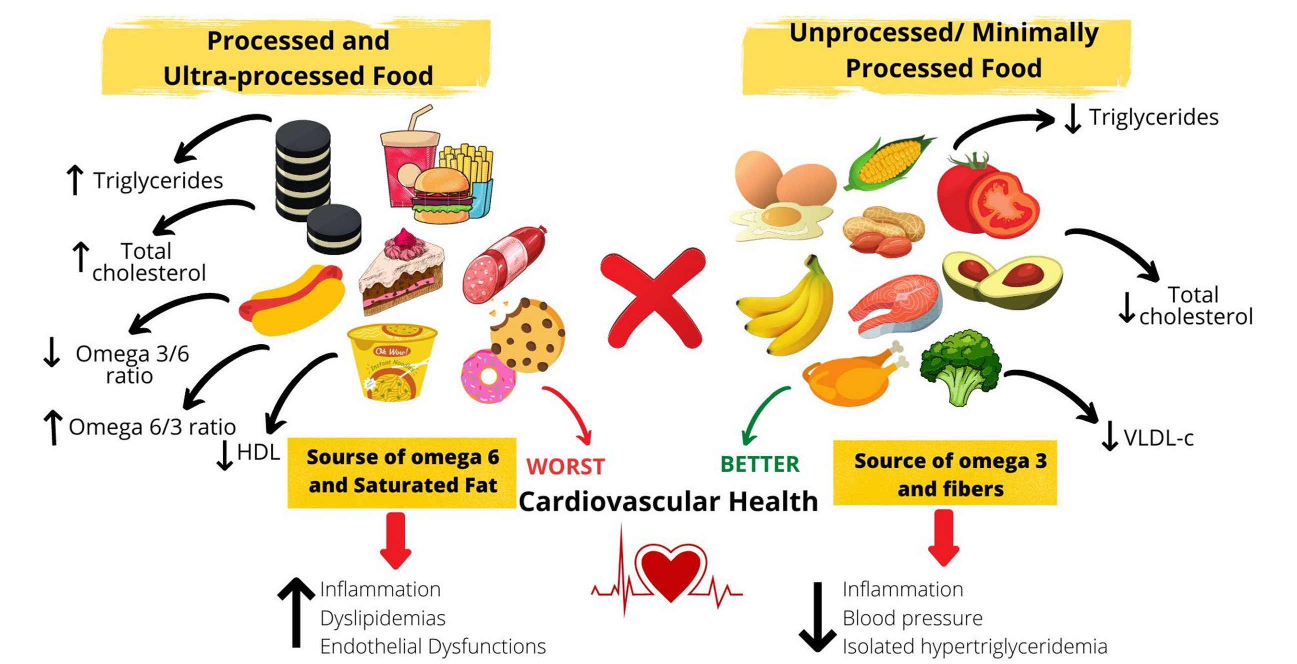

FIGURE 2
Impact of consumption of processed food, according to degree of processing, on serum fatty acids and the consequences.

metabolic syndrome; one of the components of this syndrome is the presence of HDL-c below the recommendations, which was the most common one in the study of Tavares et al. (57, 58). Moreover, Sofi et al. (2018) observed that vegetarian and Mediterranean diets were able to reduce the levels of TG, TC, and LDL-c in individuals after 3 months of the intervention (59). Together, the findings indicate a possibly beneficial effect of the consumption of foods with a low degree of processing on metabolic parameters, whereas increased consumption of processed food may be associated with the development of chronic non-communicable diseases.

It is already well-established in the literature that the consumption of foods rich in fiber can reduce the risk of hypertriglyceridemia (60). Dietary fibers increase the excretion of cholesterol-rich bile salts and reduce fat absorption by the intestine (61). Thus, the cardioprotective factor of the consumption of unprocessed food may partially explain the negative association with hypertriglyceridemia as well the high prevalence of dyslipidemia in women in the present study, since the average consumption of unprocessed food was between 1–4 times a week while processed and ultra-processed foods were at least once a week, contradicting the guidelines of the Food Guide for the Brazilian Population (36).

On the other hand, the high consumption of saturated and trans-fat, sugar, and additives presented in processed and ultra-processed food might favor dyslipidemia, inflammation, and cardiovascular disease. Saturated fatty acids are associated with worse metabolic outcomes due to their ability to impair hepatic glucose and lipid metabolism, favoring atherosclerosis and hypertriglyceridemia (62) they also promote insulin resistance (63), stress oxidative, and activate inflammatory signaling, through the Toll-like receptor (TLR) (64). Meanwhile, the excess of sugar in the diet is converted and oxidized to form acetyl-coenzyme A, a molecule necessary for the synthesis of triglycerides via lipogenesis again, favoring lipid imbalance (65). In addition, excessive sugar consumption leads to hyperglycemia, which in turn activates the *NF-KappaB* transcription factor, activating inflammatory pathways (66, 67).

In summary, the results highlight the importance of the degree of processing food in the fatty acids and lipid profile (Figure 2), emphasizing the effort of public health strategy to improve diet quality among the population, specially in patients with severe obesity, where the cardiometabolic risk is already increased (9). It is important to note that other factors, not evaluated in this study, might influence fatty acids and lipid profile, such as sleep hours and quality (68), sedentary behavior, tabagism, and presence of other diseases and genetics; and should be investigated in future studies (69, 70).

One of the limitations of the present work was the convenience study. Also, the cross sectional study does not allow causality conclusions, thus, the present results must be confirmed in longitudinal and populational study. A larger sample size could have produced stronger correlations between the variables. However, it is important to highlight that despite the sample size, several associations were found between the variables examined in this study; the sample power showed 0.80. Furthermore, because of the absence of consumption frequency data for specific foods, we could not identify specific foods that could contribute to the associations found in this study.

On the other hand, the present study is a pioneer in investigating the effect of the consumption of foods categorized using a recent classification established according to the degree of processing on the fatty acid profile, which is a metabolic parameter that is still not widely explored. Furthermore, this work can be considered relevant since it studied a population of women who belonged to a category of nutritional status that has not been examined extensively, despite its importance.

5. Conclusion

The present study observed negative associations between the consumption of processed and ultra-processed food with unfavorable lipid profiles and fatty acid levels in women with severe obesity, whereas unprocessed/minimally processed food favors lipid profile. It is the role of nutrition to reinforce that processed and ultra-processed foods should be avoided not only because of the caloric excess they offer, but also because of the nutritional quality that can have deleterious effects on health. These results emphasize the importance of understanding the effect of food consumption in Depper biomarkers of the metabolism and how this can impact health and disease, showing the need for further studies in different populations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving humans were approved by Research Ethics Committee of the Federal University of Goiás (Number 3.251.178) and the Ethical Committee of Research of the Dr. Alberto Rassi State Hospital (HGG) (Number 3.392.511). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

KL and FC: responsible for the writing of the original draft. KL, NF, FK, EO, GP, and FC: reviewing and editing the manuscript. KL, LO, ADâ, RW, GP, and FC: acquisition, analysis, or interpretation of data. KL, GL, MH, VS, ADu, GP, and FC: conceptualization of the study, statistical analysis, and accessed the database and raw data. FC: supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2023.1046710/full#supplementary-material

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