

Research Paper

Association between animal and plant protein intake and obesity: a cross-sectional analysis of data from the study of cardiovascular risk in adolescents (ERICA)

Liliana Paula Bricarello^{a,*}, Mariane de Almeida Alves^b, Bernardo Paz Barboza^c, Anabelle Retondario^d, Camila Tureck^e, Ricardo Fernandes^f, Amanda de Moura Souza^g, Francisco de Assis Guedes de Vasconcelos^a

^a Post-graduate Program in Nutrition at the Federal University of Santa Catarina, Brazil

^b Fundació Institut Universitari per a la recerca a l'Atenció Primària de Salut Jordi Gol i Gurina (IDIAPJGol), Barcelona, Spain

^c School of Medicine and Surgery, Università Degli Studi di Milano-Bicocca, Italy

^d Department of Nutrition, Federal University of Paraná, Brazil

^e Avantis University Center - UNIAVAN, Santa Catarina, Brazil

^f Faculty of Health Sciences, Federal University of Grande Dourados, Brazil

^g Public Health Institute, Federal University of Rio de Janeiro, Brazil

ARTICLE INFO

Handling Editor: Dr. A. Siani

Keywords:

Animal protein

Plant protein

Obesity

Cross-sectional study

Adolescents

ABSTRACT

Background and aims: Obesity among children and adolescents aged 5 to 19 years has increased dramatically. This study aimed to investigate the association of animal protein intake (API) and plant protein intake (PPI) with obesity in adolescents aged 12 to 17 years.

Methods and results: This cross-sectional study used data from 70,332 adolescents who participated in the Study of Cardiovascular Risk in Adolescents (ERICA). Dietary intake of animal and plant proteins was assessed using a 24-h dietary recall (24HR). Protein intake was stratified into quintiles based on the percentage of total energy derived from this nutrient. Associations between protein intake and obesity were estimated using logistic regression models, adjusted for age, type of school (used as a proxy for income), physical activity level, and total energy intake. All models were stratified by sex. Among boys, those in the fourth and fifth quintiles of API had 75% and 91% higher odds of obesity, respectively. Among girls, there was a trend toward increased odds of obesity, although it was not statistically significant. Higher odds of abdominal obesity were observed for both sexes in the two highest quintiles of API intake (girls: OR1.26, 95% CI 1.03–1.54; boys: OR1.78, 95% CI 1.29–2.46). As for PPI, lower odds of abdominal obesity were observed only among girls in the fourth quintile (OR0.80, 95% CI 0.65–0.98).

Conclusion: Our findings suggest that despite the multifactorial nature of obesity, reducing API and increasing PPI may help decrease the odds of general and abdominal obesity among adolescents.

1. Introduction

Globally, according to the World Health Organization (WHO), obesity among children and adolescents aged 5 to 19 years has increased dramatically between 1990 and 2022. In 1990, the prevalence of obesity in this age group was 2.0% (31 million), whereas in 2022, it reached 8% (160 million) [1]. It is projected that by 2050, 15.6% of individuals aged 5 to 14 years (186 million) and 14.2% of those aged 15 to 24 years (175 million) will be living with obesity [2].

Given the complex and multifactorial nature of obesity [1], identifying its associated factors has been the subject of extensive scientific investigation. Among these, diet has emerged as a key contributor in the causal pathway of obesity and other non-communicable chronic diseases [3–5]. The diet of Brazilian adolescents is characterized by the consumption of traditional foods, such as rice and beans, high intake of sugar-sweetened beverages and ultra-processed foods [6]. Within the dietary components, protein plays a critical role in adolescent growth and development, as adequate intake is essential for supporting muscle

* Corresponding author.

E-mail address: liliana.bricarello@ufsc.br (L.P. Bricarello).

<https://doi.org/10.1016/j.numecd.2026.104703>

Received 2 September 2025; Received in revised form 10 March 2026; Accepted 12 March 2026

Available online 14 March 2026

0939-4753/© 2026 The Authors. Published by Elsevier B.V. on behalf of The Italian Diabetes Society, the Italian Society for the Study of Atherosclerosis, the Italian Society of Human Nutrition and the Department of Clinical Medicine and Surgery, Federico II University. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

mass gain, erythrocyte and myoglobin synthesis, and hormonal changes during this life stage [7].

High-protein diets are commonly employed in strategies to manage obesity due to their potential effects on increasing satiety, enhancing diet-induced thermogenesis, and preserving lean body mass during weight loss, which together may facilitate body weight regulation. However, depending on the source of protein, we can find different associations with health outcomes [8]. Accordingly, several studies have examined the relationship between the intake of animal- and plant-based protein sources and obesity in adolescents. In a study of 3443 Israeli adolescents aged 11 to 18 years (52% female), Dor et al. (2022) found that dietary protein intake—predominantly from non-dairy animal sources such as beef and poultry—was positively associated with overweight and obesity [9]. Regarding plant and animal protein, Lin et al. (2015), analyzing data from 1804 European adolescents (53% female; mean age: 14.7 years, range: 12.5–17.4), reported an inverse association between Plant Protein Intake (PPI) and both body mass index (BMI) and body fat percentage (%BF), while Animal Protein Intake (API) was positively associated with BMI and %BF [10]. Similarly, Segovia-Siapco et al. (2020), studying 530 adolescents in Southern California and Michigan (56% female, aged 12–18 years), found that higher total and API were positively associated with obesity [11].

Therefore, it is important to investigate the association between API and PPI and obesity among Brazilian adolescents. Such evidence may contribute to current dietary protein intake recommendations and help guide individuals in making healthier food choices. It is worth noting that, to date, no studies have assessed the relationship between API and PPI and obesity using a representative sample of Brazilian adolescents. Thus, this study aimed to investigate the association between API and PPI and obesity in adolescents aged 12 to 17 years participating in the Estudo de Riscos Cardiovasculares em Adolescentes (ERICA, Study of Cardiovascular Risk in Adolescents).

2. Methods

2.1. Study design, participants, and ethical considerations

This cross-sectional study utilized data from ERICA, a multicenter, school-based survey conducted across all regions of Brazil [12]. National data collection took place between 2013 and 2014 and included all federal units—comprising the 27 state capitals and five additional macro-regions that encompassed cities with populations over 100,000. The sample consisted of 71,740 adolescents aged 12 to 17 years, enrolled in 1247 public and private schools across 124 municipalities nationwide. Data collection teams received standardized training to minimize measurement bias and ensure methodological consistency [13]. For the present analysis, only adolescents with complete data for the first 24-h dietary recall were included. Participants with total energy intake at or below the 1st percentile (≤ 561 kcal/day) or at or above the 99th percentile (≥ 6168.6 kcal/day) were excluded.

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were followed, as detailed in [Supplementary Material 1](#). The ERICA study was approved by the Research Ethics Committee of the Institute for Collective Health Studies at the Federal University of Rio de Janeiro (approval no. 01/2009, protocol no. 45/2008), as well as by the ethics committees of all 26 Brazilian states and the Federal District. All participants signed an assent form.

2.2. Questionnaires

Three questionnaires were administered in the ERICA study to gather information about the adolescents, their families, and their schools. For the present study, data from the first questionnaire were used. This questionnaire was self-administered by the adolescents at their schools using an electronic data collection device (Personal Digital Assistant, PDA). It included questions on sociodemographic characteristics,

employment, physical activity, alcohol consumption, smoking, diet, oral health, reproductive health, self-reported morbidity, common mental disorders, and sleep [12].

2.3. 24-Hour dietary recall

A 24-h dietary recall (24H) was conducted with all adolescents in the sample through individual interviews, employing the Multiple Pass Method (MPM) [14]. The recalls were recorded on an offline laptop, with data subsequently entered into the ERICA-REC24h system and uploaded to a central server [12]. Nutritional composition analysis was carried out using the food composition table from Household Budget Survey (POF 2008-2009) and the Nutritional Data System for Research (NDSR) software's Food and Nutrient Database, developed and maintained by the United States Department of Agriculture (USDA) [15,16].

2.4. Protein intake

Reported foods were grouped into 36 categories based on macronutrient similarities, namely: 1) Rice, 2) Mixed rice with animal protein, 3) Legumes (beans and other legumes), 4) Mixed legumes with animal protein, 5) Corn (corn and corn-based preparations), 6) Mixed corn with animal protein, 7) Leafy greens (lettuce, kale, cabbage, among others), 8) Vegetables, roots and tubers, 9) Oilseeds (chestnuts, walnuts, peanuts), 10) Flours, pasta and bakery products, 11) Ultra-processed flours and bakery products, 12) Ultra-processed cereals, 13) Cereals, 14) Cakes and biscuits, 15) Ultra-processed cakes and biscuits, 16) Meats (preparations with beef, pork, offal, others), 17) Ultra-processed meats, 18) Poultry, 19) Poultry ultra-processed foods, 20) Eggs, 21) Fish and seafood, 22) Dairy products and milk-based preparations, 23) Ultra-processed dairy products, 24) Sweets, 25) Ultra-processed sweets, 26) Oils and fats, 27) Ultra-processed oils and fats, 28) Ultra-processed sugary drinks, 29) Sugary drinks, 30) Coffee and tea, 31) Ultra-processed coffee/tea-based drinks, 32) Alcoholic beverages, 33) Ultra-processed snacks, 34) Mixed preparations, 35) Fried mixed preparations, and 36) Condiments. API was calculated from the protein content of animal-based foods (e.g., meats, dairy products, eggs, fish), while PPI was calculated from the protein content of plant-based foods (e.g., legumes, cereals, vegetables, nuts). Animal and plant protein intake was determined using the NDSR nutritional composition table [16], based on the quantity (in grams) of each food item reported by the adolescents.

The percentage of total energy derived from protein intake (both animal and plant-based) was then calculated, considering 4 kcal of energy per gram of protein. Finally, this value was categorized into quintiles to classify individuals according to their intake of both protein types.

2.5. Anthropometric measurements

Anthropometric measurements were taken in duplicate by a trained team [12,13]. Weight, height, and waist circumference data were collected. Weight was measured using an electronic scale (Lider® P150 m) with a maximum capacity of 200 kg and a precision of 50 g. Height was measured in duplicate using a portable stadiometer (Alturaexata®) with an accuracy of 0.1 cm (a maximum variation of 0.5 cm between measurements was allowed, and the mean was calculated). For weight and height measurements, adolescents were barefoot, wearing light clothing, and standing upright. Body mass index (BMI) was then calculated as weight (kg) divided by height squared (m^2) [12,13]. Obesity classification followed the World Health Organization (WHO) growth curves based on BMI-for-age z-scores [17–19], with obesity defined as a z-score $> +2$. Waist circumference was measured using a non-elastic anthropometric tape (Sanny®), with a maximum length of 1.5 m and a precision of 1 mm. Two waist circumference measurements were taken at the midpoint between the iliac crest and the lowest rib [12]. The values were recorded directly in the PDA, and the mean of the

two measurements was calculated [12]. Waist circumference was classified as adequate (below the 90th percentile for adolescents aged 12–15 years and/or < 90 cm for boys or < 80 cm for girls aged 16–17 years) or elevated (≥ 90 th percentile for adolescents aged 12–15 years and/or ≥ 90 cm for boys or ≥ 80 cm for girls aged 16–17 years) [20].

2.6. Theoretical analysis model

To identify potential confounding factors, a theoretical model was developed based on available scientific evidence (Fig. 1). This model was constructed using causal diagram theory [21] and directed acyclic graphs (DAGs) [22]. In Fig. 1, the theoretical model depicts the association between protein intake ((●)) and obesity ((●)), connected by a unidirectional grey line. Measured variables exclusively associated with exposure—screen time, sleep, and sexual maturation—are shown as dark grey. Parental overweight is an unobserved variable associated exclusively with exposure and is shown as grey spirals. Screen time is associated with obesity through physical inactivity and consequently lower energy expenditure [23–25]. Sleep is also a risk factor for obesity, as insufficient and/or poor-quality sleep increases fatigue, affects food intake, and may lead to obesity [24,26]. During adolescence, nutritional status may be more strongly influenced by sexual maturation than chronological age; literature reports an association between post-pubertal stage and obesity [27]. Parental nutritional status is another known risk factor, influenced by both genetic factors (appetite regulation, metabolism, fat storage) and lifestyle habits in the family environment [24,25]. Variables associated with both protein intake and obesity—energy intake, physical activity, age, sex, and socioeconomic status—are presented in white and considered confounders.

Family socioeconomic status influences lifestyle and, consequently, dietary intake and nutritional status [25,28,29]. Similarly, energy intake is directly associated with both exposure and outcome [19,25,30], while physical activity is inversely associated with obesity [19,25,31,32]. Sex and age are individual characteristics linked to both exposure and outcome. Females tend to consume less protein than males [6,33]. Body composition changes during puberty, with girls tending to gain fat mass and boys tending to lose total body fat [34]. Age during adolescence is also directly associated with both obesity and protein intake, especially among boys [27,35,36].

Ultra-processed food intake also appears in the theoretical model (light grey), associated with both obesity and protein intake. However, since its association with protein intake is mediated by energy intake, it does not require adjustment.

Thus, the following variables were identified as confounders in the theoretical model and are depicted in white: energy intake, physical activity, age, sex, and socioeconomic status (school type was used as a proxy based on the assumption that students in private schools have a higher socioeconomic level and are correlated with family income or parents' education in Brazil) [12]. Among these, sex was used as a stratification variable. By adjusting for this set of variables, all backdoor paths were blocked, and confounding was removed from the model (Fig. 1) [21,22].

2.7. Statistical analysis

Descriptive analyses were initially conducted to characterize the study population (sex, age, type of school, physical activity level, and prevalence of total obesity and elevated waist circumference—abdominal obesity). Variables were described using means and standard deviations, medians and interquartile ranges, or frequencies, according to the type and distribution of the data. Protein intake as a percentage of total energy intake (%E), from both animal and plant sources, categorized into quintiles, was considered the exposure variable. The outcomes were total obesity and abdominal obesity, both treated as binary variables (yes or no).

Associations between protein intake and obesity measures were estimated using logistic regression models, adjusted for age, type of school (used as a proxy for income), and total energy intake. All models were stratified by sex. Analyses accounted for sampling weights and the complex survey design.

The presence of a non-linear pattern (U-shaped) in the relationship between exposure and outcome was investigated by analyzing the predicted probabilities from the model.

To indirectly evaluate the possibility of residual confounding, three approaches were adopted: (1) comparison between crude and adjusted models, considering a variation >10% in coefficients as indicative of potential confounding; (2) assessment of overall model fit using McFadden's and adjusted McFadden's pseudo R^2 , with values between

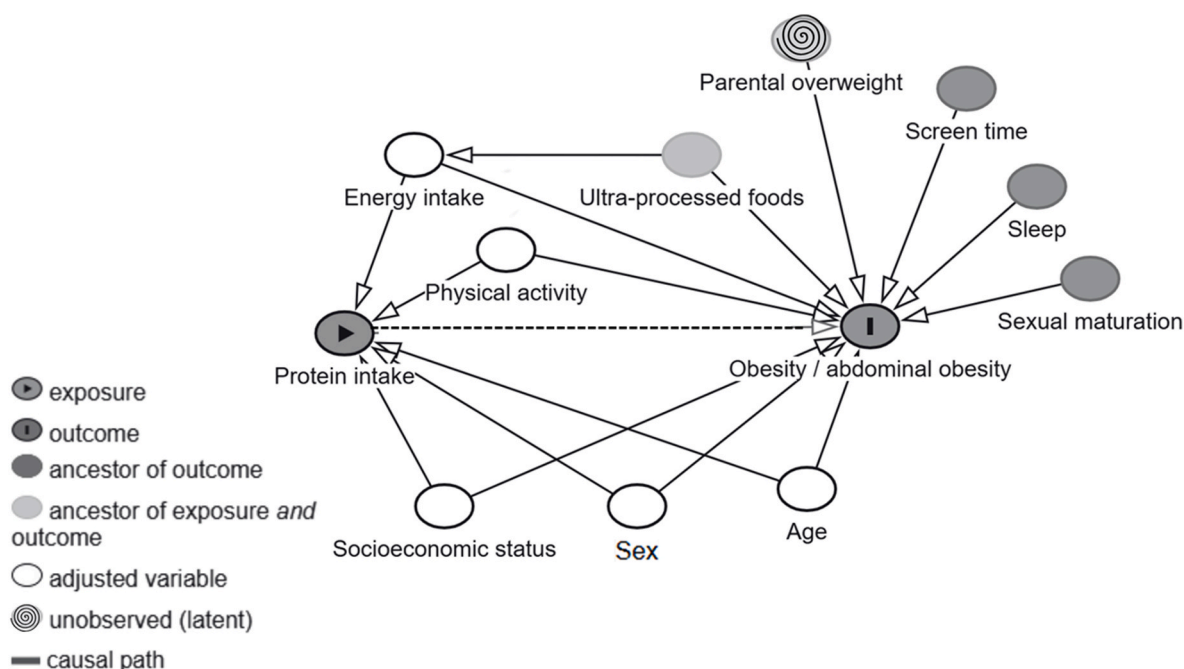


Fig. 1. Theoretical model of analysis illustrating the association between protein intake and obesity/abdominal obesity.

0.2 and 0.4 interpreted as evidence of satisfactory fit; and (3) sensitivity analysis for unmeasured confounding using the E-value, with values > 2 considered indicative of a relatively robust association, that is, with a low likelihood of being explained by an unmeasured confounder.

Statistical analyses were performed using STATA® version 18, and p-values ≤ 0.05 were considered statistically significant.

3. Results

3.1. Participant characteristics

A total of 691 adolescents with total energy intake ≤ 1st percentile (561 kcal/day) and 717 ≥ 99th percentile (6168.6 kcal/day) were excluded. The final analytical sample comprised 70,332 adolescents aged 12 to 17 years who participated in the ERICA study. Of these, 55.4% were female, 78.5% attended public schools, 7.8% were classified as having obesity, and 10.3% as having abdominal obesity (Table 1). Data were stratified into quintiles of %E from animal and plant protein sources. API was higher than PPI in both grams per day and %E.

Statistically significant differences were found in the means of BMI ($p < 0.001$), WC ($p < 0.001$), and energy intake ($p < 0.001$) across quintiles of %E from animal protein sources, indicating that at least one group differed significantly from the others. In contrast, no significant differences were observed across quintiles for age ($p = 0.563$) or physical activity level ($p = 0.846$). For %E from plant protein sources, energy intake was significantly different across quintiles ($p < 0.001$) (Table 1). Fig. 2 shows the average BMI and WC in all quintiles of %E of animal and vegetable protein sources.

Regarding categorical variables, statistically significant associations were found between API quintiles and sex, type of school, obesity, and abdominal obesity (all $p < 0.001$). For PPI, however, significant associations were limited to sex ($p = 0.004$) and type of school ($p = 0.008$), as shown in Table 1.

3.2. Associations between protein intake, obesity, and abdominal obesity

Table 2 presents the associations between quintiles of %E from API and the presence of obesity and abdominal obesity. Among female adolescents, no significant association was found between API and obesity.

In contrast, male adolescents in the fourth and fifth quintiles had 75% and 91% higher odds of obesity, respectively, compared to those in the first quintile. Regarding abdominal obesity, higher odds were observed in both sexes among individuals in the two highest quintiles of API (females: OR 1.26, 95% CI 1.03–1.53; males: OR 1.78, 95% CI 1.29–2.46).

Table 3 presents the associations between quintiles of %E from PPI and the presence of obesity and abdominal obesity. Among female adolescents, higher relative intake of plant protein was associated with lower odds of both outcomes; however, statistical significance was observed only for abdominal obesity. Girls in the fourth quintile had a significantly lower likelihood of abdominal obesity compared to those in the first quintile (OR 0.80, 95% CI 0.65–0.98). Among male adolescents, no clear association was found between PPI and either obesity or abdominal obesity, and none of the odds ratio estimates reached statistical significance [Insert Table 3].

There was no evidence of a U-shape in the relationship between exposure and outcome. For the percentage of energy from animal protein, the sensitivity analysis for unmeasured confounding showed E-values > 2 in the higher quintiles (Q4 and/or Q5), suggesting that the significant associations observed are unlikely to be explained by residual confounding. Model fit was satisfactory, with McFadden's and adjusted McFadden's pseudo R^2 values between 0.2 and 0.4 (Supplementary Materials 2 and 3).

4. Discussion

Based on the available literature, this appears to be the first study to examine the association between API and PPI and obesity—including abdominal obesity—in a nationally representative sample of Brazilian adolescents. Among boys, higher odds of obesity were observed in those in the fourth and fifth quintiles of API. A higher likelihood of abdominal obesity was found in individuals of both sexes who were in the two highest quintiles of API. Regarding PPI, lower odds of abdominal obesity were observed only among girls in the fourth quintile compared with the first.

Corroborating the findings of this study, Jen et al. (2018), who assessed boys and girls aged 8 to 10 in the Netherlands, also found that API (%E) was positively associated with obesity [37]. Similarly,

Table 1

Characteristics of participants in the Study of Cardiovascular Risk in Adolescents (ERICA), by sociodemographic variables, stratified by quintiles of animal and PPI (% of total energy). Brazil, 2013–2014.

	All participants (n = 70,332)	Q1: animal protein (%E)	Q5: animal protein (%E)	p-value	Q1: plant protein (%E)	Q5: plant protein (%E)	p-value
Animal protein, g (Median/IQR)	48.9 (30.5 to 74.6)	19.8 (11.7 to 29.8)	93.4 (66.1 to 130.2)	<0.001 ^α	52.8 (31.3 to 83.9)	39.2 (24.3 to 59.9)	<0.001 ^α
Plant protein, g (Median/IQR)	16.8 (9.4 to 25.7)	17.9 (9.8 to 28.0)	12.5 (6.4 to 20.2)	<0.001 ^α	4.5 (2.2 to 7.7)	30.4 (22.2 to 40.6)	<0.001 ^α
Animal protein, %E (Median/IQR)	9.5 (6.3 to 13.4)	3.8 (2.6 to 4.8)	18.1 (16.0 to 21.7)	<0.001 ^α	10.5 (6.4 to 15.8)	8.5 (5.8 to 11.7)	<0.001 ^α
Plant protein, %E (Median/IQR)	3.2 (1.9 to 4.6)	3.3 (1.9 to 4.9)	2.6 (1.4 to 4.0)	<0.001 ^α	1.0 (0.5 to 1.3)	6.1 (5.5 to 7.2)	<0.001 ^α
Age, years (Median/IQR)	15 (13 to 16)	15 (13 to 16)	15 (13 to 16)	0.563 ^α	15 (13 to 16)	15 (13 to 16)	0.070 ^α
BMI, kg/m ² (Mean/SD)	21.2 (4.1)	20.9 (4.0)	21.7 (4.3)	<0.001 ^α	21.2 (4.1)	21.2 (4.2)	0.869 ^α
WC, cm (Mean/SD)	71.5 (9.6)	70.8 (9.2)	72.6 (10.0)	<0.001 ^α	71.4 (9.6)	71.8 (9.8)	0.311 ^α
Energy intake, kcal (Mean/SD)	2289.7 (1005.7)	2391.6 (1104.5)	2150.6 (968.8)	<0.001 ^α	2294.2 (1073.1)	2036.9 (872.9)	<0.001 ^α
PA, min/week (Median/IQR)	300 (62 to 710)	275 (60 to 700)	300 (70 to 700)	0.846 ^α	270 (50 to 665)	300 (75 to 720)	0.185 ^α
Sex				<0.001 ^β			0.004 ^β
Female (%)	38.951 (55.4)	7.880 (57.0)	7.625 (54.1)		8.232 (59.3)	7.109 (50.4)	
Male (%)	31.381 (44.6)	5.940 (43.0)	6.469 (45.9)		5.643 (40.7)	7.011 (49.7)	
Type of school				<0.001 ^β			0.008 ^β
Public (%)	55.177 (78.5)	11.548 (83.6)	10.316 (73.2)		11.074 (79.8)	2.801 (20.2)	
Private (%)	15.155 (21.6)	2.272 (16.4)	3.778 (26.8)		11.283 (79.9)	2.837 (20.1)	
Obesity (%)	5.513 (7.8)	923 (6.7)	1.337 (9.5)	<0.001 ^β	1.083 (7.8)	1.213 (8.6)	0.662 ^β
Abdominal obesity (%)	7.220 (10.3)	1.034 (9.4)	1.751 (12.4)	<0.001 ^β	1.475 (10.6)	1.459 (10.4)	0.305 ^β

Q1: Lowest quintile; Q5: Highest quintile g: grams; IQR: Interquartile range; WC: Waist circumference; BMI: body mass index; %E: % of energy; PA: Physical activity; α: Survey-weighted linear regression with F-test for overall group differences; β: Survey-weighted chi-squared test.

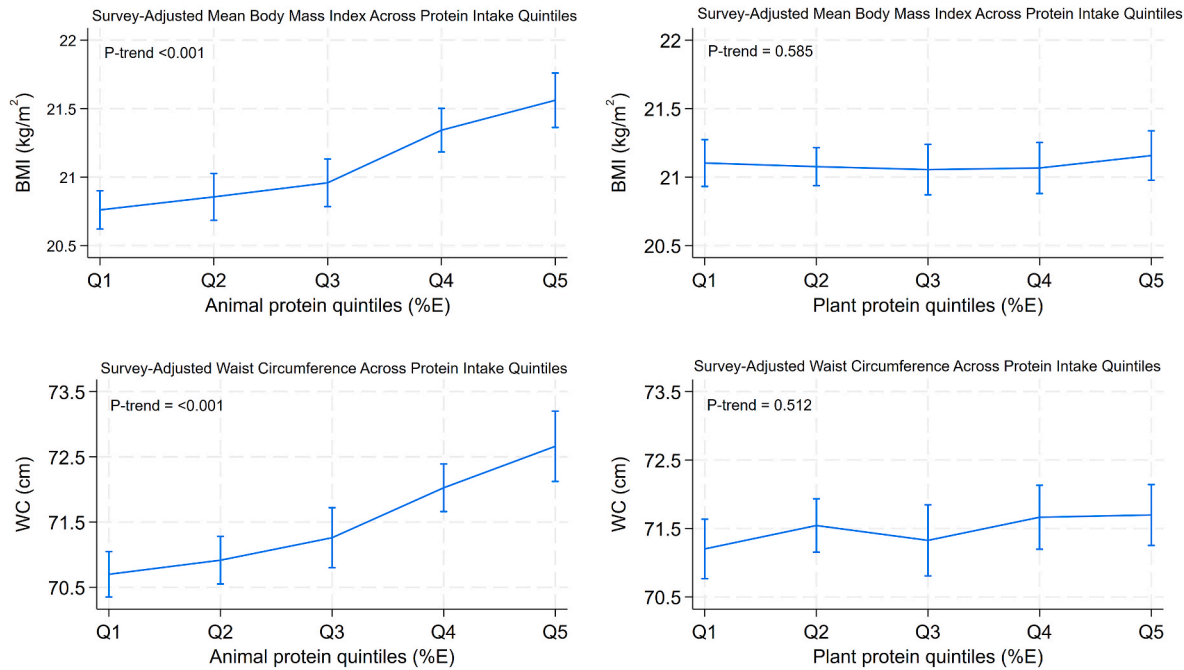


Fig. 2. Means of BMI and WC across quintiles of %E from animal protein and plant protein sources.
Footnote: ¹ The analyses were weighted and took into account the sampling design.

Table 2
Odds ratios (OR) and 95% confidence intervals (CI) for the association between quintiles of API (% of energy) and obesity indicators, stratified by sex. ERICA, Brazil, 2013–2014.

	Obesity*				Abdominal obesity**			
	Female ^a		Male ^b		Female ^c		Male ^d	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
% E from animal protein								
Q1	1.00	-	1.00	-	1.00	-	1.00	-
Q2	0.94	0.68; 1.31	1.24	0.95; 1.63	1.03	0.83; 1.27	1.04	0.77; 1.41
Q3	0.91	0.64; 1.30	1.19	0.92; 1.54	0.95	0.76; 1.18	1.08	0.79; 1.46
Q4	1.15	0.82; 1.62	1.75	1.30; 2.34	1.23	1.04; 1.46	1.39	1.02; 1.91
Q5	1.14	0.82; 1.59	1.91	1.39; 2.64	1.26	1.03; 1.53	1.78	1.29; 2.46

Models adjusted for age, type of school (as a proxy for income), physical activity (minutes/week), and total energy intake. * Obesity defined as BMI-for-age z-score > +2. ** Abdominal obesity was defined as elevated waist circumference based on age- and sex-specific cutoffs. a: P-trend = 0.263. b: P-trend <0.001. c: P-trend = 0.005. d: P-trend <0.001. P-trend was calculated by entering quintiles as an ordinal continuous variable (1–5) in the adjusted survey-weighted logistic regression model and testing the coefficient (design-based Wald test).

Segovia-Siapco et al. (2020), in a study with adolescents aged 12 to 18 in the United States, reported a positive association between API (g/day) and obesity, and also found that higher intake of animal protein was associated with abdominal obesity [38]. Lin et al. (2011), who assessed adolescents and adults aged 15 years and older in Belgium, observed a positive association between API (%E) and both obesity and abdominal obesity, although the results were significant only for males [39].

In contrast, Lin et al. (2015), who studied adolescents from eight European countries, found that API (%E) was positively associated with obesity, but API in g/day showed no such association [10]. Similarly, Dor et al. (2022) reported that adolescents classified as overweight or obese had a higher mean API (%E) compared to their normal-weight peers. Nevertheless, no such difference was found when API was

Table 3
Odds ratios (OR) and 95% confidence intervals (CI) for the association between quintiles of PPI (% of total energy) and obesity indicators, stratified by sex. ERICA, Brazil, 2013–2014.

	Obesity*				Abdominal obesity**			
	Female ^a		Male ^b		Female ^c		Male ^d	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
% E from plant protein								
Q1	1.00	-	1.00	-	1.00	-	1.00	-
Q2	0.96	0.71; 1.30	1.16	0.87; 1.57	0.92	0.73; 1.15	1.15	0.86; 1.55
Q3	0.88	0.66; 1.18	1.09	0.82; 1.46	0.84	0.67; 1.05	1.13	0.83; 1.54
Q4	0.75	0.55; 1.01	0.99	0.76; 1.30	0.80	0.65; 0.98	0.96	0.71; 1.29
Q5	0.83	0.58; 1.19	1.15	0.87; 1.51	0.81	0.64; 1.03	1.04	0.76; 1.43

Models adjusted for age, type of school (as a proxy for income), physical activity (minutes/week), and total energy intake. * Obesity defined as BMI-for-age z-score > +2. ** Abdominal obesity was defined as elevated waist circumference based on age- and sex-specific cutoffs. a: P-trend = 0.147. b: P-trend = 0.711. c: P-trend = 0.031. d: P-trend = 0.759. P-trend was calculated by entering quintiles as an ordinal continuous variable (1–5) in the adjusted survey-weighted logistic regression model and testing the coefficient (design-based Wald test).

assessed in g/day [9]. The discrepancy between these findings suggests that the unit of measurement (whether %E or g/day) used in statistical models may influence the outcomes. In regression analysis, the interpretation of "a one-unit increase" varies depending on how the variable is expressed—whether in %E or g/day—which can lead to different associations. Researchers should be attentive to these methodological factors when working with variables that can be expressed in multiple ways [40].

In the present study, API exceeded PPI both in grams per day and as a percentage of energy. The food groups that contributed most to API were red meat, poultry, and mixed preparations; fish and seafood; dairy products; and milk-based preparations. For PPI, the main contributors were legumes; pasta and baked goods; mixed preparations; sugar-

sweetened beverages/juices; and vegetables, roots, and tubers (data not shown). Although sugar-sweetened beverages/juices and plant-based drinks contribute significantly to the total intake of plant-origin foods, it is important to recognize that not all plant-derived products confer the same health benefits. Sugar-sweetened beverages, despite their plant-based ingredients, often have low nutritional value and have been linked to increased risks of obesity, type 2 diabetes, and cardiovascular disease. This distinction aligns with food classification systems that differentiate minimally processed foods — consistently associated with positive health outcomes — from ultra-processed products, which may attenuate or negate these benefits. Therefore, dietary assessments and recommendations should account for differences in processing level and nutritional quality within plant-based food groups to accurately reflect their impact on health outcomes [41].

A meta-analysis by Rouhani et al. (2014) identified high consumption of red and processed meats as a risk factor for obesity, as evidenced by increased BMI and abdominal obesity [42]. While it is unlikely that a single nutrient alone accounts for the development of obesity, animal protein-rich foods are often energy-dense, mainly due to their high levels of cholesterol and saturated fat.

Some mechanisms have been proposed to explain the positive association between API and obesity/abdominal obesity, as well as the inverse association between PPI and obesity. API appears to be involved in the potential stimulation of insulin [43] and insulin-like growth factor-1 (IGF-1) [44]. IGF-1 has been associated with the proliferation and differentiation of pre-adipocytes into mature adipocytes [45]. On the other hand, plant-based diets — especially vegan diets — have been linked to lower circulating levels of total IGF-1 and higher levels of IGF-binding proteins (IGFBP-1 and IGFBP-2), suggesting that lower animal protein intake is associated with lower IGF-1 levels [46].

Sex differences in the observed associations may be related to hormonal changes during puberty, which may modulate the effects of dietary protein. Leptin, a hormone secreted by adipocytes, plays an essential role in regulating food intake and energy expenditure [47]. Notably, leptin increases differently in males and females during pubertal development: in boys, leptin levels rise before and during the early stages of puberty, whereas in girls, leptin levels increase progressively throughout puberty [48]. As noted by Lin et al. (2015), PPI may stimulate serum leptin via homeostatic mechanisms, thereby influencing body weight and fat percentage [10]. On the other hand, healthy eating habits and behaviors are influenced by several factors, and these associations differ by sex [49]. Future studies are needed to further clarify the role and underlying mechanisms of dietary protein in the development and progression of obesity and abdominal obesity in adolescents, as well as sex-specific differences in these associations.

These findings highlight the importance of promoting dietary strategies that prioritize protein-rich foods from plant sources—such as vegetables, fruits, whole grains, legumes, and nuts—as well as regional and minimally processed options. At the same time, the consumption of animal-based foods, particularly red and processed meats, should be limited or included in moderation, with consideration for both human health and environmental sustainability [50]. Furthermore, public policies are needed to reduce the intake of ultra-processed protein sources of both plant and animal origin, in alignment with the recommendations of the Brazilian Dietary Guidelines (2014) [51].

The present study has several strengths, including its large sample size, national representativeness, school-based population, use of the MPM, use of photographic records to estimate portion sizes, and application of the 24HR, a tool capable of capturing dietary variability in a continental-sized country as Brazil. Moreover, all anthropometric measurements were performed by trained professionals, minimizing the risk of data collection errors. In addition, our findings bring valuable insights into the dietary habits of Brazilian adolescents. They may support the development of targeted nutrition and public health policies for adolescents with obesity or abdominal obesity. Lastly, we used a DAG to identify confounders, and it seems unlikely that an unmeasured

confounder with the magnitude observed in the E-value was not included in the model, considering the variables assessed.

Nonetheless, some limitations must be acknowledged. As a cross-sectional study, causal relationships cannot be established; therefore, prospective and intervention studies are needed to confirm these findings. Furthermore, in studies of obesity, reverse causality is a major confounder. Adolescents with higher Body Mass Index (BMI) may have different eating patterns or higher absolute caloric needs, leading to increased animal protein consumption. Conversely, those already struggling with obesity may have altered their diets prior to the study. It is also important to note that this study design captures only a single point in time, which limits its ability to characterize the developmental trajectory of obesity amid the rapid physiological changes that occur during adolescence.

Another limitation is the absence of detailed data necessary to classify all protein-rich foods and accurately estimate protein intake, particularly in the case of mixed preparations. While BMI is a strong predictor of obesity at the population level, additional body composition measures — such as lean mass and fat mass — would provide more comprehensive insights. These limitations highlight the need for further research into the differential effects of animal and plant protein on body composition in adolescents.

5. Conclusions

Our findings show that higher intake of animal protein is associated with increased odds of obesity and abdominal obesity among boys, as well as with abdominal obesity among girls. For plant-based protein, there was evidence of a linear trend across percentage of energy quintiles for abdominal obesity only for girls.

Animal protein intake, expressed both in grams (g/day) and as a percentage of total energy (E%), was substantially higher than plant protein intake, indicating that animal sources were the main contributors to protein intake. Our findings suggest that lower animal protein intake is associated with more favorable obesity-related outcomes, while no significant association was observed for plant protein intake. However, given the cross-sectional design, causal inferences cannot be established. Further prospective studies and intervention trials are needed to confirm these associations and to evaluate the long-term safety of high-protein diets in this age group.

In line with the One Health framework promoted by the WHO, these findings support dietary patterns based on plant-derived foods, with only modest inclusion of animal-source foods.

Funding

L.P.B. is a postdoctoral student in the Graduate Program in Nutrition at the Federal University of Santa Catarina and currently receives a Junior Postdoctoral Scholarship from FAPESC/CNPq (*Fundação de Amparo à Pesquisa e Inovação de Santa Catarina*) under Public Call No. 38/2022, a support program for applied research aimed at retaining young researchers in the state of Santa Catarina (Brazil).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.numecd.2026.104703>.

References

- [1] World Health Organization. Obesity and overweight [Internet]. Geneva: WHO. Available from: <http://www.who.int/en/news-room/fact-sheets/detail/obesity-and-overweight>. [Accessed 10 June 2025].
- [2] Kerr JA, et al. Global, regional, and national prevalence of child and adolescent overweight and obesity, 1990–2021, with forecasts to 2050: a forecasting study for the global Burden of Disease Study 2021. *Lancet* 2025;405(10481):785–812.
- [3] Jebeile H, Kelly AS, O'Malley G, et al. Obesity in children and adolescents: epidemiology, causes, assessment, and management. *Lancet Diabetes Endocrinol* 2022;10(5):351–65.
- [4] Larray-García A, Mahmood L, Miguel-Berges ML, et al. Diet quality scores, obesity and metabolic syndrome in children and adolescents: a systematic review and meta-analysis. *Curr Obes Rep* 2024;13(4):755–88.
- [5] Mescoloto SB, Pongiluppi G, Domene SMA. Ultra-processed food consumption and children and adolescents' health. *J Pediatr* 2024;100(Suppl 1):S18–30. Suppl 1.
- [6] Souza AM, Barufaldi LA, Abreu GA, Giannini DT, Oliveira CL, Santos MM, et al. ERICA: intake of macro and micronutrients of Brazilian adolescents. *Rev Saude Publica* 2016;50(Suppl 1):5s. <https://doi.org/10.1590/S01518-8787.2016050006698>.
- [7] Savarino G, Corsello A, Corsello G. Macronutrient balance and micronutrient amounts through growth and development. *Ital J Pediatr* 2021;47:109.
- [8] Lv JL, Wu QJ, Li XY, Gao C, Xu MZ, Yang J, Zhang ST, Luan J, Cai DZ, Chang Q, Zhao YH. Dietary protein and multiple health outcomes: an umbrella review of systematic reviews and meta-analyses of observational studies. *Clin Nutr* 2022 Aug; 41(8):1759–69. <https://doi.org/10.1016/j.clnu.2022.06.005>. Epub 2022 Jun 20. PMID: 35810569.
- [9] Dor C, Stark AH, Dichtiar R, et al. Non-Dairy animal protein consumption is positively associated with overweight and obesity in Israeli adolescents. *Foods* 2022;11:2072.
- [10] Lin Y, Mouratidou T, Vereecken C, et al. Dietary animal and plant protein intakes and their associations with obesity and cardio-metabolic indicators in European adolescents: the HELENA cross-sectional study. *Nutr J* 2015;14:10.
- [11] Segovia-Siapco G, Khayef G, Pribis P, et al. Animal protein intake is associated with general adiposity in adolescents: the teen food and development Study. *Nutrients* 2020;12:110.
- [12] Bloch KV, Szklo M, Kuschner MC, et al. The Study of Cardiovascular Risk in Adolescents-ERICA: rationale, design and sample characteristics of a national survey examining cardiovascular risk factor profile in Brazilian adolescents. *BMC Public Health* 2015;15:94.
- [13] Vasconcellos MT, Silva PL, Szklo M, et al. Sampling design for the Study of Cardiovascular Risks in Adolescents (ERICA). *Cad Saude Publica* 2015;31:921–30.
- [14] Conway JM, Ingwersen LA, Vinyard BT, et al. Effectiveness of the US Department of Agriculture 5-step multiple-pass method in assessing food intake in obese and nonobese women. *Am J Clin Nutr* 2003;77:1171–8.
- [15] Instituto Brasileiro de Geografia e Estatística. Pesquisa de Orçamentos Familiares (POF), 2008-2009: tabela de composição nutricional dos alimentos consumidos no Brasil. Rio de Janeiro (RJ): Instituto Brasileiro de Geografia e Estatística; 2011. Available from: <http://biblioteca.ibge.gov.br/visualizacao/livros/liv50000.pdf>. [Accessed 10 August 2025].
- [16] Haytowitz DB, Ahuja JKC, Wu X, Somanchi M, Nickle M, Nguyen QA, et al. USDA national nutrient database for standard reference, legacy release. Nutrient data laboratory, Beltsville Human Nutrition research Center, ARS, USDA. 2019. <https://doi.org/10.15482/USDA.ADC.1529216>.
- [17] Lohman T, Roche A, Martorell R. Anthropometric standardization reference manual. Champaign (IL): Human Kinetics Books; 1988.
- [18] Onis M, Onyango A, Borghi E, et al. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* 2007;85:660–7.
- [19] World Health Organization (WHO). Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organ Tech Rep Ser* 2000; 894(i–xii):1–253.
- [20] International Diabetes Federation (IDF). The IDF consensus definition of the metabolic syndrome in children and adolescents. Brussels: IDF; 2007.
- [21] Glymour MM, Greenland S. Causal diagrams. In: Rothman KJ, Greenland S, Lash TL, editors. *Modern epidemiology*. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2008. p. 183–209.
- [22] Cortes TR, Faerstein E, Struchiner CJ. Utilização de diagramas causais em epidemiologia: um exemplo de aplicação em situação de confusão. *Cad Saude Publica* 2016;32:e00050315.
- [23] Kumar A. Factors associated with obesity in children. *Int J Hum Sci* 2012;9(2): 805–14.
- [24] World Health Organization (WHO). Interim report of the Commission on Ending Childhood Obesity. Geneva: WHO; 2015.
- [25] Pereira FT, Domingues SC, Santos MG. The complexity of childhood obesity: factors, impacts and solutions. *World J Biol Pharm Health Sci* 2024;6(1):1–10.
- [26] Lee JH, Cho J. Sleep and obesity. *Sleep Med Clin* 2022;17(1):111–6.
- [27] Lima NMDS, Leal VS, Oliveira JS, Andrade MIS, Santos NFD, Pessoa JT, et al. Excess weight in adolescents and associated factors: data from the ERICA study. *J Pediatr* 2021;97(6):676–84. <https://doi.org/10.1016/j.jpeds.2021.02.008>.
- [28] Beenackers MA, Kamphuis CB, Giskes K, et al. Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. *Int J Behav Nutr Phys Act* 2012;9:116.
- [29] Narciso J, Silva AJ, Rodrigues V, Monteiro MJ, Almeida A, Saavedra R, et al. Behavioral, contextual and biological factors associated with obesity during adolescence: a systematic review. *PLoS One* 2019;14(4):e0214941. <https://doi.org/10.1371/journal.pone.0214941>.
- [30] Boucher AB, Adesanya EA, Owei I, et al. Dietary habits and leisure-time physical activity in relation to adiposity, dyslipidemia, and incident dysglycemia in the pathobiology of prediabetes in a biracial cohort study. *Metabolism* 2015;64(8): 1060–7.
- [31] Schwartz C, King NA, Perreira B, Blundell JE, Thivel D. A systematic review and meta-analysis of energy and macronutrient intake responses to physical activity interventions in children and adolescents with obesity. *Pediatr Obes* 2017;12(3): 179–94. <https://doi.org/10.1111/ijpo.12124>.
- [32] Stripp TA, Sangild PT. Holistic approaches to explain and combat obesity. *Nat Metab* 2025. <https://doi.org/10.1038/s42255-024-01197-3>.
- [33] O'Bree E, Soyiri I, Johnstone A. Investigating predictors of protein intake in an adult population utilising the National Health and Nutrition Examination (NHANES) Survey in the United States. *Proc Nutr Soc* 2024;83(OCE2):E227. <https://doi.org/10.1017/S0029665124004518>.
- [34] Kelsey MM, Zeitler PS. Insulin resistance of puberty. *Curr Diab Rep* 2016;16:75. <https://doi.org/10.1007/s11892-016-0751-5>.
- [35] Hoy MK, Clemens JC, Moshfegh A. Protein Intake of Adolescents: what we eat in America, NHANES 2015–2016. In: FSRG dietary data briefs [Internet]. Beltsville (MD): USDA; 2021 Jan. Dietary Data Brief No. 30. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK588791/>.
- [36] Garcia-Iborra M, Castanys-Munoz E, Oliveros E, Ramirez M. Optimal protein intake in healthy children and adolescents: evaluating Current evidence. *Nutrients* 2023; 15(7):1683. <https://doi.org/10.3390/nu15071683>.
- [37] Jen V, Karagounis LG, Jaddoe VVW, Franco OH, Voortman T. Dietary protein intake in school-age children and detailed measures of body composition: the Generation R study. *Int J Obes* 2018;42(10):1715–23. <https://doi.org/10.1038/s41366-018-0098-x>.
- [38] Segovia-Siapco G, Khayef G, Pribis P, Oda K, Haddad E, Sabaté J. Animal protein intake is associated with general adiposity in adolescents: the Teen Food and Development Study. *Nutrients* 2019;12(1):110. <https://doi.org/10.3390/nu12010110>.
- [39] Lin Y, Bolca S, Vandevijvere S, De Vriese S, Mouratidou T, De Neve M, et al. Plant and animal protein intake and its association with overweight and obesity among the Belgian population. *Br J Nutr* 2011;105(7):1106–16. <https://doi.org/10.1017/S0007114510004642>.
- [40] Bricarello LP, Barboza BP, Retondario A, Fernandes R, Tureck C, de Almeida Alves M, et al. Association between animal protein intake and overweight/obesity: a systematic review and meta-analysis of observational studies. *Nutr Metab Cardiovasc Dis* 2025;104027. <https://doi.org/10.1016/j.numecd.2025.104027>.
- [41] Violi G, Kalmourtzidou A, Cena H. Exploring benefits and barriers of plant-based diets: health, environmental impact, food accessibility and acceptability. *Nutrients* 2023;15(22):4723. <https://doi.org/10.3390/nu15224723>.
- [42] Rouhani MH, Salehi-Abargouei A, Surkan PJ, Azadbakht L. Is there a relationship between red or processed meat intake and obesity? A systematic review and meta-analysis of observational studies. *Obes Rev* 2014;15(9):740–8. <https://doi.org/10.1111/obr.12172>.
- [43] Voortman T, van den Hooven EH, Tieleman MJ, Hofman A, Kieft-de Jong JC, Jaddoe VW, et al. Protein intake in early childhood and cardiometabolic health at school age: the Generation R Study. *Eur J Nutr* 2016;55(6):2117–27. <https://doi.org/10.1007/s00394-015-1026-7>.
- [44] Hoppe C, Udam TR, Lauritzen L, Mølgaard C, Juul A, Michaelsen KF. Animal protein intake, serum insulin-like growth factor I, and growth in healthy 2.5-y-old Danish children. *Am J Clin Nutr* 2004;80(2):447–52. <https://doi.org/10.1093/ajcn/80.2.447>.
- [45] Wabitsch M, Hauner H, Heinze E, Teller WM. The role of growth hormone/insulin-like growth factors in adipocyte differentiation. *Metabolism* 1995;44(10 Suppl 4): 45–9. [https://doi.org/10.1016/0026-0495\(95\)90220-1](https://doi.org/10.1016/0026-0495(95)90220-1).
- [46] Allen NE, Appleby PN, Davey GK, Kaaks R, Rinaldi S, Key TJ. The associations of diet with serum insulin-like growth factor I and its main binding proteins in 292 women meat-eaters, vegetarians, and vegans. *Cancer Epidemiol Biomarkers Prev* 2002;11(11):1441–8.
- [47] Mejia-Montilla J, Reyna-Villasamil N, Fernández-Ramírez A, Reyna-Villas E. Leptina, obesidad y enfermedades cardiovasculares. *Repert Med Cir* 2023;32(3): 218–27. <https://doi.org/10.31260/RepertMedCir.01217372.1243>.
- [48] Lordelo RA, et al. Eixos hormonais na obesidade: causa ou efeito? *Arq Bras Endocrinol Metab* 2007;51(1):34–41.
- [49] Moraes ACF, Adami F, Falcão MC. Understanding the correlates of adolescents' dietary intake patterns: a multivariate analysis. *Appetite* 2012;58(3):1057–62. <https://doi.org/10.1016/j.appet.2012.01.024>.
- [50] Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, et al. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet* 2019;393(10170):447–92. [https://doi.org/10.1016/S0140-6736\(18\)31788-4](https://doi.org/10.1016/S0140-6736(18)31788-4).
- [51] Brasil. Ministério da Saúde. Secretaria de Atenção à Saúde. Departamento de Atenção Básica. Guia alimentar para a população brasileira. 2a ed. Brasília: Ministério da Saúde; 2014. 156 p.