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Influence of sugar consumption from foods with different degrees of processing on anthropometric indicators of children and adolescents after 18 months of follow-up

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Abstract
Excessive consumption of ultra-processed foods is associated with the development of metabolic changes in children and adolescents. However, the consumption of total sugars, monosaccharides and disaccharides present in these ultra-processed foods and other food groups and its association with anthropometric indicators must be evaluated. Therefore, this study aimed at analysing the influence of sugar consumption from foods with different degrees of processing on anthropometric indicators of children and adolescents after 18 months of follow-up. This cohort study was conducted among 492 children and adolescents aged 7–15 years. Information on food consumption and anthropometry was collected during three follow-up stages. NOVA classification was used for food categorisation. The influence of sugar consumption on the variation of anthropometric measurements over time was evaluated using generalised estimation equation models. During the analysis period, for each increase of 1 g/d in the consumption of total sugars and monosaccharides from ultra-processed foods, there was an increase of 0·002 kg/m^2 ($P = 0·030$) and 0·001 kg/m^2 ($P = 0·019$) in BMI/Age; increase of 0·073 ($P < 0·001$), 0·032 ($P < 0·001$) and 0·100 ($P < 0·001$) in the BMI/Age *z*-score; and increase of 0·001 cm ($P = 0·001$), 0·001 cm ($P = 0·003$) and 0·003 cm ($P < 0·001$) in waist circumference, with the consumption of total sugars, monosaccharides and disaccharides, respectively. Our study findings support the evidence that the consumption of total sugars, monosaccharides and disaccharides from ultra-processed foods is associated with weight gain and abdominal fat in children and adolescents, which may represent an important risk factor for excess weight in this age group.

Key words: Sugar consumption: NOVA: Cohort: Children: Adolescents

Food has undergone several changes over time. In general, there has been an increase in the consumption of highly processed and unhealthy foods. In many countries, dietary patterns based on healthier foods and nutrients have increased moderately during the last 20 years. However, patterns based on unhealthy items have worsened; therefore, they are outpacing the growth of healthy patterns worldwide(1). In Brazil, the consumption of ultra-processed foods such as sugary drinks increased by 16 % during 2002–2018. During the same period, traditionally consumed minimally processed foods such as rice and beans had a decrease of 37 and 52 % in terms of intake, respectively(2). These changes result from the replacement of natural and minimally processed foods by ultra-processed foods.

Considering the impact of industrial food processing on the nutritional quality of the diet and human health, a new classification depending on food processing has been developed. The NOVA classification categorises foods into four groups according to the extent and purpose of their processing: 1 – natural or minimally processed, 2 – processed culinary ingredients, 3 – processed foods and 4 – ultra-processed foods(3).

While natural foods include the edible parts of plants, animals, mushrooms, algae and water immediately after their separation from nature, minimally processed foods are the natural foods that are processed, which includes the removal of inedible or unwanted parts of the food, drying, dehydration and other methods that do not involve the addition of substances

Abbreviation: WC, waist circumference.

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such as salt, sugar, oils or fats to natural food. Processed culinary ingredients include substances extracted directly from natural or minimally processed foods or nature and that are used as culinary preparations[3]. Examples of these substances include table salt, sugar, oils and fats.

Processed foods include products in which salt or sugar, and occasionally oil, vinegar or another substance from the group of processed culinary ingredients are added to a food from group 1 – natural or minimally processed, being mostly products with two or three ingredients. Ultra-processed foods, in turn, include industrial formulations made with five or more ingredients. These ingredients include substances and additives used in the manufacture of processed foods such as sugar, oils, fats and salt, in addition to antioxidants, stabilisers and preservatives[3].

Attention must be paid to the constitution of processed and ultra-processed foods, as sugar, especially added sugars, accounts for a large part of the content of ultra-processed foods. These foods are responsible for 58·6–89·7 % of the intake of added sugars, and a 5 percentage point increase in the consumption of ultra-processed foods in the diet has led to a 1 percentage point increase in the dietary content of added sugars[4,5].

Concerns about excessive sugar consumption are explained by its association with the development of insulin resistance, hyperuricaemia, dyslipidaemia, liver steatosis, CVD and type 2 diabetes, with many of these associations occurring regardless of body weight gain or total energy intake[6]. In adolescents, high consumption of sugary drinks was associated with increased waist circumference (WC), body fat, BMI, blood pressure, serum uric acid and TAG levels, and the appearance of the metabolic syndrome[7,8]. It was also positively associated with abdominal obesity in children[9].

Although studies have analysed the consumption of ultra-processed foods and their effects on the health of children and adolescents, in addition to evaluating the proportion of added sugars present in these foods and their high intake in individuals of this age group, no prospective studies have evaluated the consumption of total sugars (intrinsic and added monosaccharides and disaccharides, or only intrinsic, in the case of natural or minimally processed foods), as well as the intake of monosaccharides and disaccharides, present not only in ultra-processed foods but also in natural or minimally processed foods, processed foods and even in sugar, which is considered as a processed culinary ingredient and its influence on the anthropometric indicators of children and adolescents.

Therefore, this study aimed to analyse the influence of sugar consumption from foods with different degrees of processing on anthropometric indicators of children and adolescents after 18 months of follow-up.

Methods

Study design and population

This is a cohort study included in the larger research ‘Metabolic Alterations Associated with Overweight/Obesity in Schoolchildren from Mutuípe – Bahia’. In the main investigation, children and adolescents aged 7–15 years, of both sexes, enrolled in elementary school in the municipality of Mutuípe, Bahia, Brazil, in 2006, were randomly selected and followed for a period of 18 months, which comprised three stages: baseline, 12 months and 18 months.

In the larger investigation, 600 children and adolescents were randomly selected; however, 108 individuals did not have data on food consumption and anthropometry in at least two stages of the follow-up, representing a loss of 18 % of the participants, who did not present significant differences for age, sex and anthropometry, when compared with the students who participated in this study. Thus, a total of 492 healthy students were included (*n* 137 children, 27·8 %; *n* 355 adolescents, 72·2 %); an informed consent form was signed by their guardians, and they had their anthropometric and food consumption information presented more than once during the study. Pregnant students, those in lactation or those with physical disabilities who prevented for the evaluation were not included. However, these conditions were not identified among the students during follow-up.

This sample had 99 and 89 % power to detect 10 % change in the mean BMI and WC of the participants, respectively, during an 18-month follow-up period[10,11]. The calculations of sampling power (1-β) used a significance level of 5 % and two-tailed tests, indicating that this sample size was sufficient to conduct unbiased estimates of the parameters of the study population[12].

This study was submitted and approved by the Ethics Committee of the School of Nutrition of the Federal University of Bahia under protocol number 03/06. This research was conducted according to the guidelines laid down in the Declaration of Helsinki. The participation of the child/adolescent in the study was dependent on the written authorisation of their guardians. The informed consent form signed by guardians was obtained from all participants.

Anthropometric measurements

The weight and height of the participants were determined according to the techniques indicated by Lohman *et al.*[13]. The measurements were taken twice, and the mean value between the two measurements was considered definitive. A portable Filizola® digital scale with a capacity of 150 kg and an accuracy of 100 g was used for measuring weight. The allowed variation between the two measurements was 0·1 kg. Height was measured using a Leicester Height Measure® stadiometer, and the measurement was recorded to the nearest 0·1 cm.

WC was measured using an inelastic fibreglass-measuring tape with a centimetre scale positioned at the midpoint between the last rib and the upper iliac crest. The reading was taken at the time of expiration. As well as weight and height, the mean of the two measurements was adopted.

Anthropometric status was evaluated using BMI based on age and WC. BMI was obtained from weight (W) and height (H), using the following formula: BMI = W (kg)/H^2 (m). Anthropometric variables were used in their continuous form. To characterise the sample, BMI was classified according to the *z*-score cut-off points recommended by the WHO by Onis *et al.*[14] for individuals aged 5–19 years according to sex and age.

As for WC, the measurement values in centimetres were used to assess the abdominal fat. Considering that there is no consensus on the cut-off point for WC in children and adolescents, the 90th percentile of the sample was used in this study to classify as having 'excess abdominal fat' for a participant with a value above the 90th percentile of the sample and as 'adequate' for a student with a value below this percentile, as proposed by Freedman *et al.*[15].

Lifestyle and socio-demographic data

Lifestyle information was collected at baseline, at 12 and 18 months of follow-up, totalling three measures over time. However, considering the small variability of socio-demographic conditions among students in the follow-up period, this information was only collected at baseline.

Lifestyle and socio-demographic information were provided by the mothers or guardians of the children or adolescents and recorded using a structured questionnaire. Demographic information included information on the sex and age of the students. Socio-economic conditions involved questions about the number of rooms, number of people living in the house, main type of lighting and occupation of the head of the family and gave rise to the socio-economic index. These questions had the answers scored from 0 to 4, ranging from 0 (worst condition) to 4 (best condition). Thus, the socio-economic index had a minimum score of 0 and a maximum of 16.

Considering that maternal education is associated with socio-economic conditions and cultural and dietary aspects of the society in which the individual is located[16], this information was evaluated separately as an adjustment variable.

Lifestyle was assessed by the practice of physical activity, time spent on screen and the consumption of alcoholic beverages and cigarettes. The level of physical activity was evaluated depending on an instrument produced by the research team, consisting mainly of a structured questionnaire with questions referring to the frequency of physical activity practice not included in the school pedagogical content. This tool used to assess physical activity is a variation of the International Physical Activity Questionnaire, and this was previously validated in Brazil por Matsudo *et al.*[17]. Therefore, depending on the degree of physical activity practised by the student, the participant was classified as active when the physical activity practice was two or more days outside of school and as not very active/sedentary when the physical activity practice was less than 2 d outside of school in addition to the physical activity level, it was also asked if the student consumed alcoholic beverages and smoked, and screen time was also evaluated, in which the amount in hours per day that child/adolescent watched TV was asked. Screen time > 3 h/d was considered 'high'.

Dietary evaluation

Food consumption was evaluated using the 24-h recall applied in person at each stage by trained researchers, totalling to three recalls. The parents or guardians of the participants were involved at the time of collection. The students were asked about the food and beverages consumed 24 h before the interview, including details of the preparations. Information on the consumption of sweets (candies, bonbons, chocolates, ice cream, chewing gum, among others), water and alcoholic beverages was also collected and recorded.

Twenty-four-hour recalls were coded by trained staff to assess food consumption. Subsequently, the preparations were separated and the portions of food and beverages ingested in homemade measures were converted into grams or millilitres using a guide to estimate food consumption[18]. The breakdown of preparations into ingredients allowed for an increase in nutritional information quality; improvement in the quantification of energy, macro and micronutrients and greater detail in determining the amount of each ingested item, allowing their classification into food groups.

After the preparations were separated, the amount of each food and/or ingredient in grams or millilitres was entered in the nutrient and food groups calculation programme Nutrition Data System for Research (NDS-R) 2017 version of the University of Minnesota[19]. Nutrition Data System for Research is linked to a dietary database of American origin, and therefore, for the entry of food information from the recordings, we used the publication of the GAC (Food Consumption Assessment Research Group of the Faculty of Public Health of the University of São Paulo) as a guide, which contains the description of the English equivalents of foods consumed nationally, which are available in the programme database[20].

After entering the information from the recalls into the Nutrition Data System for Research programme, a consistency analysis was performed for each food recall by period to identify outliers, which may be caused by errors in data collection and/or processing[20]. The values of daily energy consumption below 2,092 kJ (500 kcal) or above 29,288 kJ (7,000 kcal) were considered extreme[21]. Four recalls whose daily energy intake was less than 2,092 kJ (500 kcal) were identified. After identifying these outliers, data were excluded from the analysis.

Considering the purpose of the study, the database resulting from the consistency analysis was analysed and each recall by period was analysed to identify and exclude only foods that did not contain sugars and/or fibre in their composition. After identification, these foods were excluded from the database to be used in the analysis of food groups. Only foods that contained sugar and/or fibre remained in the database. These foods were categorised according to the classification by Monteiro *et al.*[3] into: group 1 – natural and minimally processed foods; group 2 – processed culinary ingredients; group 3 – processed foods and group 4 – ultra-processed foods. The following foods were identified from the dietary recalls of the participants:

Group 1 – Natural and minimally processed foods. Coconut water, cassava, fresh peanuts, unsalted roasted peanuts, andu, white rice, brown rice, oat flakes, sweet potatoes, potatoes, ground coffee, instant coffee, sugarcane juice, ground cinnamon, cashew nuts unsalted toast, powdered barley, natural fennel tea, wheat bran, linseed flour, cassava flour, maize flour, common wheat flour, beans (carioca, fradinho, white, green and black), various fruits, maize meal, yam, various vegetables, liquid coconut milk, powdered skimmed milk, liquid and powdered whole milk, noodles (common and for lasagna), mangalô, white maize, fresh maize, popcorn, chicken egg, pepper, black pepper, soyabeans, natural orange juice, natural lemon juice, natural tomato juice, raisins and various vegetables.

Group 2 – Processed culinary ingredients. White sugar, icing sugar, brown sugar, fresh and dry biological yeast, salted butter, honey and vinegar.

Group 3 – Processed foods. Plum in syrup, roasted peanuts with salt, homemade sugary sweet potato, sun-dried meat, beef jerky, sweetened grated coconut, pickled mushroom, homemade pineapple jam, pickled peas, breadcrumbs, pickled green maize, paçoca, potato bread, milk bread, maize bread, French bread, rennet cheese, mozzarella cheese, grated parmesan cheese, provolone cheese, dried tomato (preserved in oil – drained), bacon and red wine.

Group 4 – Ultra-processed foods. Chocolate powder and liquid, praline peanuts, Japanese peanuts, candies, potato chips, water and salt biscuit, American biscuit, chocolate covered biscuit, common and wholegrain cream cracker biscuit, coconut biscuit, buttery sweet biscuit without filling, maize starch biscuit, Maria biscuit, biscuit filled with various flavours, donut biscuit, salty biscuit without filling, seven-layer biscuit, wafer biscuit various flavours, breakfast cereal, chewing gum, milk and white chocolate bars, filled chocolate, confetti type chocolate, whipping cream, industrialised milk candy, vanilla essence, milk flour, common ice cream various flavours, flavoured gelatine, industrialised jelly, guava paste, granola, yogurt various flavours, gum drops, ketchup, condensed milk, mortadella, mustard, white and wholegrain loaf of bread, hot dog bread, microwave popcorn, industrialised sweet popcorn, industrialised salted popcorn, lollipops, chicken ham, textured soya protein, soft drink various flavours, common and light cream cheese, salami, maize chips various flavours, pepper snacks, common and chicken sausage, soft ice cream machines, powdered and liquid artificial juice various flavours and instant noodle seasoning various flavours.

After categorising the foods, the amounts in grams of fructose, galactose and glucose were added to estimate the group of monosaccharides, and the amount of lactose, sucrose and maltose to obtain the disaccharide group. The amounts of total fibre, total sugars, disaccharides and monosaccharides of each group were estimated at each study period (baseline, 12 months and 18 months) in spreadsheets of the Microsoft Excel programme version 365 personal[22].

The online version of the Multiple Source Method was used to estimate habitual consumption of sugars and total energy to adjust the data for the 3-d consumption according to intrapersonal variation, that is, to remove the random variability attributed to the individual (intra-individual variance)[23]. As this analysis referred to the consumption of macronutrients and energy and there were no data obtained from FFQ, all participants were assumed as regular consumers. After adjustments by the Multiple Source Method, the information for each nutrient was adjusted as a function of the habitual energy, using the residual method[24]. After adjustment, they were used to build generalised estimation equation models.

Statistical analysis

The descriptive characteristics of the sample were presented as proportions, means, standard deviation and mean differences in the paired samples, obtained using Stata 12.0 software[25].

To evaluate the influence of dietary intake of sugars from foods with different degrees of processing on the variation of BMI, BMI/Age z-score and WC over time, generalised estimation equation models were built with an autoregressive working correlation matrix, appropriate for continuous and time-varying outcomes[26,27]. To assess the relationships of interest, a model was constructed for each outcome variable, which was included in its longitudinal continuous form (BMI, BMI/Age z-score and WC) as a function of each main exposure variable (intake of sugars from each processing group). Initially, univariate analyses were performed to select candidate variables for the multivariate model, and those with a P-value of less than 20 % were selected. These variables were included in the model as covariates. In the final model, the variables that had statistical significance lower than 5 % remained.

To evaluate the fit of the final model, the quasi-likelihood criterion under the corrected independence model (QICc) was used, which is a modification of the Akaike's information criterion method. The QICc is calculated by comparing the quasi-likelihood of the independence model with the complete model. The smaller the QICc, the better the fit of the model[28,29]. The generalised estimation equation analyses were performed using the Stata statistical package version 12.0[25].

Results

Sample characteristics

A total of 492 children and adolescents were studied, of which 72·15 % were aged 10 years or older (mean age 10·99 (SD 2·13) years). In the total sample, 58·34 % were women, most of the participants were sedentary (78·66 %) and 84·14 % of the students spent more than 3 h/day on screens. Regarding the consumption of alcoholic beverages and cigarettes, there were no smokers and only 0·4 % (n 2) reported using alcoholic beverages (data not shown in the table). Table 1 presents the characteristics of the sample according to information on age, sex and lifestyle.

Anthropometric status

Regarding anthropometric status, there was no significant change in the number of individuals with underweight, normal weight, overweight and high WC (> 90th percentile) over the 18 months. During this period, most students (above 90 %) were healthy. However, there was a 400 % increase in the number of children and adolescents who developed obesity at the end of the investigation compared with that in the initial period. Considering BMI/Age and the BMI/Age z-score, there was a significant increase in the mean values at 12 and 18 months compared with that in the initial period of the investigation. However, for WC, the increase was significant only at mean of 12 months compared with the mean at baseline (Table 1).

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Consumption of food groups

The mean energy intake was 1773·66 (SD 633·93) kcal/d. All individuals consumed all food groups during the evaluated period. The foods constantly consumed and foods with the highest mean amount ingested belonged to groups 1 and 4 (Table 2), with the natural and minimally processed food group having the highest mean consumption and the highest mean energy consumption (777·91 (SD 335·77) g/d and 819·49 (SD 400·26) kcal/d, respectively), followed by the ultra-processed food group (140·94 (SD 154·29) g/d and 367·46 (SD 320·58) kcal/d, in that order). Foods in group 3 were usually less consumed, and the mean amount ingested and mean energy intake of these processed foods were 110·30 (SD 85·13) g/d and 343·80 (SD 263·59) kcal/d, respectively. Group 2, which included culinary ingredients, had the lowest mean amount ingested: 39·72 (SD 31·66) g/d. Consequently, the lowest mean energy consumption was 183·19 (SD 155·31) kcal/d (Table 2), compared with that of other food groups.

Regarding the average amount of sugars consumed daily (Table 2), due to its composition characterised by more monosaccharides, foods in group 1 had the highest average daily intake of these macronutrients (12·15 (SD 14·07) g/d), while group 2, for having 'table sugar' (sucrose) as the most ingested ingredient among the participants, resulted in the highest mean amount of disaccharides consumption (28·50 (SD 23·31) g/d) among the food groups. The group 4, for containing foods with high sugars content, had the highest average amount of total sugars consumption (30·39 (SD 36·76) g/d). Although it did not present higher average amounts of sugars, group 3 demonstrated a balance between the average amounts consumed of the evaluated nutrients.

Sugar consumption and anthropometric status

Regarding sugar consumption and anthropometric indicators, Table 3 presents the unadjusted and adjusted results of the generalised estimation equation analyses for the consumption of sugars in the group of natural and minimally processed foods and the anthropometric status. For each increase of 1 g/d in the consumption of monosaccharides from natural and minimally processed foods, there was an increase of 0·057 kg/m^2 ($P = 0·041$) in the mean BMI/Age, and this increase remained significant in the adjusted model, although the increase in the mean was smaller (0·005 kg/m^2, $P = 0·047$), over the 18-month follow-up. The results were not statistically significant for total sugars and disaccharides. As shown in Table 3, an increased consumption of total sugars from natural and minimally

Table 1. General characteristics of the students evaluated according to each stage of the study. Mutuípe, Bahia, Brazil, 2006–2008
(Mean values and standard deviations; numbers and percentages)

	Baseline		12 months		18 months	
	n	%	*n*	%	*n*	%
Age (≥ 10 years)	355	72·15				
Male sex	205	41·66				
Screen time (> 3 h/d)	414	84·14				
Physical activity (active)	105	21·34				
Weight deficit†	6	1·30	9	1·90	3	0·70
Healthy	452	94·20	445	91·90	372	92·10
Overweight	21	4·40	29	6·00	24	5·90
Obese	1	0·20	1	0·20	5	1·20*
High WC (> 90th percentile)	45	9·90	49	10·00	41	10·00
	Mean	SD	Mean	SD	Mean	SD
BMI (kg/m^2)	18·09	3·12	18·68	3·35*	17·99	3·08*
BMI (*z*-score)	–0·02	1·14	0·20	1·17*	0·41	1·21*
Waist circumference (cm)	64·69	8·83	65·82	8·68*	64·80	9·02

WC, waist circumference.
* *P*-value < 0·05, calculated using paired *t* test for dependent samples by comparison with baseline.
† < *z*-score –2 of the BMI/Age for individuals aged 5–19 years according to sex and age.

Table 2. Average daily consumption of the food groups and sugars. Mutuípe, Bahia, Brazil, 2006–2008
(Mean values and standard deviations)

	Average consumption (g/d)		Average energy consumption (kcal/d)		Average amount of monosaccharides (g/d)		Average amount of disaccharides (g/d)		Average amount of total sugars (g/d)	
Food group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group 1 – natural or minimally processed	777·91	335·77	819·49	400·26	12·15	14·07	13·23	10·43	25·28	21·49
Group 2 – processed culinary ingredients	39·72	31·66	183·19	155·31	0·43	1·52	28·50	23·31	28·93	23·82
Group 3 – processed foods	110·30	85·13	343·80	263·59	1·89	2·58	5·07	4·64	7·00	6·20
Group 4 – ultra-processed foods	140·94	154·29	367·46	320·58	11·18	19·67	17·61	23·12	30·39	36·76

processed foods led to an increase in the mean BMI/Age z-score of the participants and this increase remained significant ($P < 0.001$) after adjustment for total dietary fibre, energy, socio-economic status, physical activity and maternal education. For monosaccharides, the increase remained significant even after adjustment ($P < 0.001$). For disaccharides, the result was significant only after adjustment ($P < 0.001$); however, there was reduction of 0·058 in the mean BMI/Age z-score. Regarding the WC indicator, only total sugars did not change this indicator over time. After adjustment for covariates, monosaccharides promoted a significant increase of 0·003 cm ($P = 0.034$) and disaccharides promoted a significant reduction of 0·001 cm ($P = 0.020$) in the mean of this indicator.

Over the 18-month follow-up, for each increase of 1 g/d in the consumption of total sugars (including intrinsic and added monosaccharides and disaccharides) from ultra-processed foods, there was an increase of 0·034 kg/m^2 in the mean BMI/Age ($P = 0.001$) of the individuals. This association remained significant after adjusting ($P = 0.030$). For the consumption of disaccharides from this food group, the result was not significant in any of the models.

There was an increase of 0·036 kg/m^2 ($P < 0.001$) in mean BMI/Age for each increase of 1 g/d in the consumption of monosaccharides from ultra-processed foods. This increase was also significant in the adjusted model, whose increase was smaller (0·001 kg/m^2, $P = 0.019$), over the 18-month follow-up (Table 3). The increase in the consumption of total sugars from ultra-processed foods led to an increase in the mean BMI/Age z-score, which continued significant after adjusting. Each increase in the 1 g/d in consumption promoted a mean increase of 0·073 in the BMI/Age z-score ($P < 0.001$) after 18 months of follow-up. A similar result was observed for monosaccharides. The increase of 1 g/d in the consumption of disaccharides from ultra-processed foods led to an increase of 0·100 ($P < 0.001$) in the mean BMI/Age of participants throughout the follow-up, after adjustment for covariates (Table 3). It was observed that every 1 g/d increase in the consumption of total sugars, monosaccharides and disaccharides in this group contributed to an increase of 0·001 cm ($P = 0.001$), 0·001 cm ($P = 0.003$) and 0·003 cm ($P < 0.001$) in the mean WC of students, respectively.

Although the consumption of sugars from processed culinary ingredients and processed foods was analysed, no statistically significant results were observed, not being presented in tables. It is noteworthy that the statistical non-significance observed for the results of these groups may be related to less frequent consumption of foods from group 3 and the small portion of processed culinary ingredients (group 2).

All models fit the data well, evaluated using the QIC criterion, reducing this indicator in the final models when compared with the unadjusted models (Table 3).

Discussion

The results obtained in this study showed that the consumption of total sugars, disaccharides and monosaccharides from ultra-processed foods, over 18 months of follow-up, promoted a significant increase in the anthropometric indicators evaluated, even after adjustment for potential confounders, while the consumption of total sugars and monosaccharides from natural and minimally processed foods, in the same period, promoted increase in some indicators and the consumption of disaccharides promoted reduction in others. The considerable increase in cases of obesity at the end of the investigation compared with that initially is also highlighted, as well as the increase in the mean of anthropometric indicators over the 18 months compared with the mean observed at baseline.

Studies evaluating children and adolescents' food consumption and its association with overweight have identified that inadequate intake of foods with high energy density (soft drinks, sweets, sweet cookies and sausages) is a risk factor for the development of overweight/obesity in adolescents, so that those whose consumption of such foods was more frequent were almost twice as likely to be overweight than individuals who adequately ingested the foods mentioned above[30]. Children who are overweight and body fat showed greater adherence to the industrialised food pattern, especially due to ultra-processed products[31], which are essentially high in energy content.

Regarding sugar consumption and its influence on anthropometric indicators, this study showed that the intake of total sugars, disaccharides and monosaccharides from ultra-processed foods was associated with an increase in anthropometric indicators. For natural and minimally processed foods, only the consumption of total sugars and monosaccharides was associated with an increase in the values of anthropometric indicators after adjustments.

Up to now, no studies were found that a longitudinal evaluation of the influence of specific consumption of sugars from foods with different degrees of processing on anthropometric indicators in children and adolescents. However, some cross-sectional and longitudinal studies verified the association between the consumption of ultra-processed foods and anthropometric markers of excess weight in this population. Costa *et al.*[32] showed a relationship between early consumption of ultra-processed foods and increased WC in children, while Louzada *et al.*[33], evaluating adolescents and adults, observed that individuals in the highest quintile of consumption of ultra-processed foods had significantly higher BMI and a greater chance of being obese or overweight than those in the lowest consumption quintile.

To understand the influence of sugars from these food groups on anthropometric indicators, it is necessary to carefully consider the effects of processing on the nutritional characteristics of foods. According to the NOVA classification[3], natural or minimally processed foods do not have added sugars in their composition, as they do not undergo industrial processing; therefore, these foods contain only intrinsic sugars in their constitution. Conversely, ultra-processed products have common sugar, invert sugar, lactose and high-fructose maize syrup, among others, added to their composition ingredients[3] to improve the palatability of many of these foods and beverages and to preserve foods, giving them desirable commercial characteristics such as viscosity, texture, body and browning ability[34,35]. Therefore, these foods naturally present sugars from the ingredients in addition to the added sugars.

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Table 3. Generalised estimation equation models for the association of the consumption of total sugars, monosaccharides and disaccharides and anthropometric indicators over 18 months of follow-up. Mutuípe, Bahia, Brazil, 2006–2008
(Coefficients and 95 % confidence values)

	BMI (kg/m²)						BMI (*z*-score)						Waist circumference (cm)					
	Unadjusted			Final model*			Unadjusted			Final model†			Unadjusted			Final model*		
Total sugars (g)	Coefficient	95 % CI	*P*	Coefficient	95 % CI	*P*	Coefficient	95 % CI	*P*	Coefficient	95 % CI	*P*	Coefficient	95 % CI	*P*	Coefficient	95 % CI	*P*
Natural and minimally processed foods	0·010	–0·025, 0·045	0·568	0·001	–0·001, 0·004	0·290	0·012	0·001, 0·023	0·032	0·120	0·085, 0·154	<0·001	0·006	–0·085, 0·098	0·887	0·001	–0·000, 0·002	0·149
Ultra-processed food	0·034	0·013, 0·054	0·001	0·002	0·000, 0·003	0·030	0·011	0·004, 0·017	0·001	0·073	0·057, 0·089	<0·001	0·103	0·048, 0·158	<0·001	0·001	0·001, 0·002	0·001
QIC		15 012·126		9841·633			1775·829			1391·073			103 852·436			66 150·680		
Monosaccharides (g)																		
Natural and minimally processed foods	0·057	0·002, 0·121	0·041	0·005	0·000, 0·009	0·047	0·027	0·008, 0·046	0·004	0·182	0·131, 0·232	<0·001	0·123	–0·017, 0·264	0·087	0·003	0·000, 0·005	0·034
Ultra-processed food	0·036	0·019, 0·054	<0·001	0·001	0·000, 0·003	0·019	0·009	0·003, 0·014	0·001	0·032	0·023, 0·040	<0·001	0·099	0·050, 0·149	<0·001	0·001	0·000, 0·002	0·003
QIC		14 657·405		9754·161			1766·967			1381·913			102 161·975			66 334·739		
Disaccharides (g)																		
Natural and minimally processed foods	–0·046	–0·116, 0·023	0·192	–0·001	–0·003, 0·000	0·134	0·004	–0·017, 0·027	0·667	–0·058	–0·077, –0·038	<0·001	–0·181	–0·363, 0·001	0·051	–0·001	–0·002, –0·000	0·020
Ultra-processed food	0·025	–0·006, 0·056	0·114	0·003	–0·000, 0·006	0·064	0·013	0·002, 0·024	0·018	0·100	0·072, 0·128	<0·001	0·097	0·013, 0·181	0·023	0·003	0·001, 0·005	<0·001
QIC		15 241·607		9852·693			1802·282			1386·271			105253,974			65 895·654		

QIC, quasi-likelihood under independence model criterion.
* Adjusted for total dietary fibre, energy, age, sex, socio-economic status, physical activity and maternal education.
† Adjusted for total dietary fibre, energy, socio-economic status, physical activity and maternal education.

Furthermore, it is important to consider that, among children and adolescents, the consumption of ultra-processed foods has been increasingly frequent. Thus, it should be noted that excessive intake of these foods can promote an increase in sugar intake and can trigger metabolic changes in individuals in this age group[7–9].

Among the most studied sugars, the metabolic effect of fructose consumption in the diet stands out. With the increase in this sugar intake, higher luminal concentrations are observed; therefore, most of the fructose molecules move to the liver to be metabolised. Unlike what occurs in glycolysis, which is strictly regulated by intracellular ATP at the level of the phosphofructokinase enzyme, fructolysis is not regulated. Consequently, phosphate trioses are produced according to the amount of fructose that enters the hepatocytes, and this process occurs regardless of the cell's energy needs. As phosphate trioses are intermediates for glycolysis, they can be used in some processes, including fatty acid synthesis through lipogenesis. However, this route requires abundant energy and occurs particularly when the fructose intake is exceptionally high[36,37], and this high intake of sugar has become very common, which results from the increasingly frequent consumption of ultra-processed foods.

Another possible mechanism is the fast phosphorylation of fructose by the fructokinase C enzyme, which results in the intracellular depletion of phosphate and the activation of AMP deaminase. AMP deaminase activation causes mitochondrial oxidative stress, leading to increased lipogenesis (with reduced aconitase and increased activation of ATP citrate lyase) and reduction of fatty acid oxidation (with reduction in enoyl CoA hydratase)[38].

Regarding the ingestion of total sugars and monosaccharides from natural and minimally processed foods, the mechanisms have not yet been elucidated. However, the mechanisms mentioned above may also apply to these sugars present in natural and minimally processed foods, as, regardless of the food source, in the present study, these sugars from both natural and minimally processed foods and ultra-processed foods seem to behave similarly. As well, it is necessary to take into account that sugar, due to its characteristic of being a source of energy, if consumed in large quantities and in high frequency, can favour weight gain. In addition, it is also necessary to consider that the beneficial effect of natural and minimally processed foods is due to the combination of the components present in these foods, which gives these foods a balanced composition of macronutrients and a significant amount of micronutrients, as they are good sources of proteins, carbohydrates and high-quality fats, in addition to fibre, vitamins and minerals[39].

It is also necessary to consider the important role of dietary fibres, since fresh and minimally processed foods are excellent sources of fibres. Due to its characteristics, dietary fibres are clinically relevant, as they can promote, through their physicochemical properties, beneficial changes for the body, such as controlling body weight, lipids and blood glucose. Through viscosity, fibres can delay gastric emptying, improving digestion and increasing satiety, as well as hindering the action of hydrolytic enzymes and thickening the barrier of the stationary water layer in the small intestine, allowing for absorption nutrient delay, especially affecting the postprandial glucose and fatty acid response. Fibres can also decrease carbohydrate absorption by including sugars in the fibre matrix and interfering with small intestine motility, affecting the entry of available carbohydrates to the mucosal surface[40–42].

The ability of fibres to associate with bile acids can also impact fat absorption and cholesterol metabolism. Since cholesterol molecules are excreted through bile acids in the faeces, it is necessary to increase the production of bile acids from the circulating cholesterol. It is also noteworthy that the increase in satiety promoted by dietary fibres can provide a reduction in food consumption in the following meals, in addition, fibre-rich foods tend to have high volume and lower energy density, leading to lower energy intake and helping to regulate body weight gain[40–42].

Although most students were healthy during the study, it is noteworthy that, even in a smaller number, there was an increase in cases of obesity in the population studied at the end of the investigation when compared with that at baseline. Despite showing a higher prevalence of obesity than at observed in this study, Flores *et al.*[43], similarly, noticed a significant chance of increasing obesity in Brazilian children and adolescents over time.

Factors such as an unhealthy diet and sedentary lifestyle may be involved in the increase in obesity cases and the means of the students' anthropometric indicators in the present study. During the analysis of food consumption, it was possible to observe that most of the individuals had a diet with a high intake of foods with high energetic density, with a high content of refined carbohydrates, especially sugars, such as sweets, ice cream, cookies and sugary drinks, in addition to the high consumption of fried foods (meat in general and snacks such as pastel and coxinha), and other foods whose composition contains considerable amounts of saturated and trans fats (savoury snacks, cookies, ice cream, instant noodles and sausages). Excessive consumption of these foods can result in changes in the body's energy balance, contributing to weight gain.

There was also a high proportion (78·66 %) of sedentary participants. This proportion was higher than that reported by Cureau *et al.*[44], who reported 54·3 % Brazilian adolescents with physical inactivity during leisure time. The high prevalence of sedentary people in this study may be related to the use of electronic media during their free time to the detriment of sports, because 84·14 % of students had spent time on screens longer than 3 h/d, which is longer than the recommendation of a maximum of 2 h/d[45].

The high proportion of sedentary students may be another cause of the increase in cases of obesity observed in individuals evaluated throughout the cohort, as low or no physical activity causes a decrease in energy expenditure, contributing to weight gain. The study conducted with Finnish children showed that the practice of physical activity in their free time and during school holidays was inversely associated with WC and waist-to-height ratio after controlling for BMI in the model[46]. In addition to a sedentary lifestyle, the long time spent in front of the screen, in addition to contributing to the reduction of energy expenditure, can lead to an increase in energy consumption, as high-energy food intake is frequent during television use, for example, in leisure for adolescents[47,48].

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Although longitudinal studies that evaluated the influence of consumption of sugars from foods of different processing degrees on anthropometric indicators in children and adolescents have not been identified, the results of this investigation indicate that the intake of total sugars, disaccharides and monosaccharides from ultra-processed foods contributed to marked changes in body weight and accumulation of abdominal fat, during follow-up, recorded in children and adolescents in the cohort. The results are even more concerning when considering that it occurs in childhood, not only because of the risk itself but also because of cardiovascular risk and other co-morbidities in early and/or late adulthood.

Furthermore, the importance of the NOVA classification is highlighted, which brought a new perspective not only on the composition of foods but also on the manufacturing process of these foods. Conventional food classifications typically categorise foods and foodstuffs based on their constituent nutrients, and dietary guidelines often adopt such classifications. However, it is noteworthy that these categorisations end up grouping foods that have different effects on health[49], for example, cereals and cereal-based products (rich in carbohydrates), recommended as staple foods for populations; however, they include not only wholegrain ones but also refined ones with a high amount of sugar, such as biscuits. And this is repeated for other types of food.

Thus, with NOVA, foods that were previously classified as recommended for consumption due to the food group to which they belonged started to be evaluated in separate groups according to the extension and purpose of their processing. This simplified classification facilitated the understanding and helped consumers to make healthier food choices, as foods with a high degree of processing are easily to recognise and can contribute to the development of chronic diseases. In addition, it is noteworthy that nutrition involves not only the intake of nutrients but also the foods that contain and supply the nutrients, the combination of foods with each other and their preparation, as well as the characteristics of the way of eating, the dimensions cultural and social aspects of eating practices[39].

However, this study has some limitations, such as the non-validation of the instrument to assess the practice of physical activity in this population, the non-application of the Tanner criteria to assess the pubertal stage of adolescent participants, although studies have shown the weaknesses of these criteria[50–52], in regarding food consumption, there are also limitations that are inherent to the method of data collection when information is self-reported, which can favour forgetting and/or omitting foods and beverages consumed in the last 24 h. It is also necessary to consider that the recalls were applied only on typical days, not happening assessment of non-typical days as on weekends. In addition, it is noteworthy that a recall was applied in each period, which may not reflect the usual intake, despite noting that food intake did not undergo major changes between days, and the method of analysis used was robust and sufficient to consider biases in the participants' food consumption.

Although the present study had limitations, the scientific evidence found in this study is consistent and robust owing to a cohort study design with well-structured follow-up, which used innovative statistical strategies appropriate to the data structure. Although further studies are needed to confirm these results, the robustness of the study design cannot be denied, as well as the care in monitoring the cohort and the biological plausibility of the associations identified here, which were previously reported by other authors.

Thus, this study can contribute to the strengthening of public policies aimed at promoting healthy eating and preventing chronic non-communicable diseases in children and adolescents, such as the increase in taxes for ultra-processed food products rich in sugars, regulation of advertising of these products aimed not only at children but also at adults, and information on packaging of these foods, among others. As well as the observed results can contribute to people's awareness about their food choices, prioritising the consumption of natural and minimally processed foods that are rich in fibre, vitamins, minerals and fats of better quality and reducing the consumption of ultra-processed foods, paying attention to the control in the intake of ingredients and processed foods. Thus, looking carefully, our findings support the evidence that the consumption of total sugars and disaccharides from ultra-processed foods and the consumption of monosaccharides from minimally processed, natural and ultra-processed foods are associated with weight gain and abdominal fat in children and adolescents, thus representing an important risk factor for overweight in this age group and contributing to overweight and the associated co-morbidities in early and/or late adulthood.

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P. R. F. C., J. C. D. P., M. L. P. S. and A. M. O. contributed to the review of the manuscript. All authors read and approved the final version of the manuscript.

The authors declare that there is no conflict of interest.

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