

Association between the consumption of antioxidant nutrients with lipid alterations and cardiometabolic risk in adolescents

Associação entre o consumo de nutrientes antioxidantes com alterações lipídicas e risco cardiometabólico em adolescentes

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ABSTRACT

Objective

This study aimed at validating the associations between the consumption of antioxidant nutrients as well as lipid alterations and cardiometabolic risks in adolescents.

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Methods

This cross-sectional study included 327 adolescents aged 14-19 years. Sociodemographic and dietary information, anthropometric and blood pressure measurements, and biochemical data were obtained. Cardiometabolic risk was calculated by aggregating the risk factors, which were expressed as the sum of Z-scores. Poisson regression was performed to estimate the prevalence ratios.

Results

In boys, low intake of zinc was associated with elevated total cholesterol and triglyceride levels, whereas it was associated with low high-density lipoprotein cholesterol levels and high low-density lipoprotein cholesterol and total cholesterol levels in girls, thus indicating a cardiometabolic risk. Furthermore, low intake of copper was associated with high triglyceride levels and cardiometabolic risk in girls. The high prevalence ratios of high low-density lipoprotein cholesterol and total cholesterol levels and cardiometabolic risk were higher in those with low intake of vitamin A. Among girls, associations were also observed between lower intake of vitamin A and high triglyceride levels. Low intake of vitamin C among boys was associated with elevated high low-density lipoprotein cholesterol and triglyceride levels. Among girls, the intake of this vitamin was associated with lower low high-density lipoprotein cholesterol levels. In girls, low intake of vitamin E was associated with low low high-density lipoprotein cholesterol levels and high total cholesterol levels.

Conclusion

The associations between antioxidant micronutrients as well as lipid alterations and cardiometabolic risk emphasize the importance of encouraging the consumption of foods that are rich in these nutrients to modulate lipid alterations and cardiometabolic risk.

Keywords: Adolescents. Antioxidants. Food consumption. Lipid metabolism disorders. Cardiovascular disease.

RESUMO

Objetivo

Esta pesquisa teve como objetivo verificar as associações entre o consumo de nutrientes antioxidantes e as alterações lipídicas e o risco cardiometabólico em adolescentes.

Métodos

Trata-se de estudo transversal com 327 adolescentes de 14 a 19 anos de idade. Investigaram-se dados sociodemográficos, antropométricos, pressóricos, bioquímicos e de consumo alimentar. O risco cardiometabólico foi calculado por meio da agregação dos fatores de risco, expressa pela soma dos escores Z. Realizou-se a regressão de Poisson para estimar as razões de prevalência.

Resultados

O baixo consumo de zinco associou-se a elevados níveis de CT e triglicérides para os meninos, e a níveis baixos de HDL-c e elevados de LDL-c e CT para as meninas, demonstrando risco. Além disso, a baixa ingestão de cobre associou-se a altos níveis de triglicérides e risco cardiometabólico para as meninas. A razão de prevalência nos níveis elevados de LDL-c, CT e risco cardiometabólico foi maior entre os adolescentes que apresentavam baixa ingestão de vitamina A. Foram observadas também associações, no sexo feminino, da menor ingestão de vitamina A com altos níveis de triglicérides. A baixa ingestão de vitamina C nos meninos mostrou associações com LDL-c e triglicérides elevado, enquanto nas meninas essa vitamina associou-se com menores níveis de HDL-c. O baixo consumo de vitamina E, para as meninas, apresentou associações com níveis baixos de HDL-c e elevados de CT.

Conclusão

As associações entre os micronutrientes antioxidantes e as alterações lipídicas e risco cardiometabólico ressaltam a importância de estimular o consumo de alimentos que sejam fonte desses nutrientes, com o objetivo de modular as alterações lipídicas e o risco cardiometabólico.

Palavras-chave: *Adolescentes. Nutrientes antioxidantes. Consumo de alimentos. Transtorno do metabolismo dos lipídeos. Doenças cardiovasculares.*

INTRODUCTION

Lipid alterations are risk factors for the development of Cardiovascular Diseases (CVD) and generally appear during infancy and adolescence; they may contribute to the development of CVD in adulthood [1]. Low-Density Lipoprotein Cholesterol (LDL-c) is responsible for transporting cholesterol to the arteries. In contrast, High-Density Lipoprotein Cholesterol (HDL-c) performs reverse cholesterol transport and has an antiatherogenic effect [2].

In cases of elevated LDL-c levels, it may become more atherogenic due to the increased oxidation of these particles. In general, oxidative stress and vascular inflammation are associated with endothelial dysfunction and vascular damage. The correlation is highly significant that pro-inflammatory alterations in the endothelial cells are considered the stimulants of cellular adhesion molecules and the release of cytokines, which are markers of endothelial dysfunction. Oxidative stress is a process that can be modulated by the consumption of antioxidant nutrients, which is similar to atherosclerosis [3-6].

Previous studies have suggested that the intake of antioxidant nutrients, such as Zinc (Zn), Copper (Cu), Selenium (Se), and vitamins A, C, and E, protect against oxidative damage and its associated complications [7-10]. A meta-analysis showed that an increase of one portion per day in the consumption of fruits and vegetables is associated with a lower risk for mortality from CVD. The risk for mortality declined by 4% for each additional portion per day of fruits and vegetables, by 5% for each additional portion per day of fruits, and by 4% for each additional portion per day of vegetables [11].

Alimentary habits adopted during adolescence are important public health concerns, considering that there is a direct association between poor dietary habits and the occurrence of obesity and other chronic diseases during adulthood [12]. The Study of Cardiovascular Risk Factors in Brazilian Adolescents showed that adolescents maintain the consumption of traditional foods, such as

rice and beans, and that the intake of sugary beverages and highly processed foods is high. Along with this alimentary profile, the excessive consumption of saturated fatty acids and free sugars and a high prevalence of inadequate intake of micronutrients were also observed [13].

Considering that studies that evaluate the consumption of antioxidant nutrients, such as Zn, Cu, and vitamins A, C, and E, in teenagers are limited and most studies have examined the association between isolated micronutrients and chronic alterations, it is important to identify the amount of micronutrients that is consumed and the association between these micronutrients and biochemical indices and the risk of developing diseases in young populations. This may then stimulate the establishment of public health policies that encourage the consumption of fruits and vegetables that are rich in these nutrients, thus improving the adolescents health over time. Therefore, this study aimed at verifying the association between the consumption of antioxidant nutrients as well as lipid alterations and cardiometabolic risk in adolescents.

METHODS

Description of the study and the population

This is a cross-sectional study on adolescents aged between 14 and 19 years who were enrolled in public and private schools in the urban area of *Teresina, Piauí*, in 2016. The study is part of a project of the *Universidade Federal do Piauí* entitled "Health in the School: A Situational Diagnosis of Secondary Schools."

Sampling plan

The schools were selected via probability sampling [14], with strata based on the type of administration and geographical area and size.

One public and one private school were selected for each size: small (up to 115 students), medium (116-215 students), and large (more than 215 students). In this study, the researcher chose the geographic area corresponding to each Regional Educational Administration (GRE), with a total of 12 public and 12 private schools.

In selecting the adolescent participants, stratified proportional random sampling was carried out [14]. The Epi Info 6.04d program (Centers for Disease Control and Prevention, Atlanta, United States of America) was utilized to calculate the minimum sample size, starting from 40,136 secondary school students in private and state public schools, which is in accordance with the 2014 School Census [15]. Moreover, 95.0% Confidence Intervals (95.0% CI) were obtained: the prevalence of obesity, 17.1% [16]; precision, 5.0%; design effect, 1.4%; and significance level, 5.0% [17]. This baseline study section required at least 304 students. Assuming that there will be a decrease in the number of participants during data collection, an additional 10.0% of the sample was randomly selected in each school, yielding a final sample of 334 adolescents.

The sample of schools that were selected was distributed in proportion to the number of adolescents per type of school administration and size, and the sample designated for each school that was selected was randomly assigned based on grade level, sex, and age.

The study was conducted in accordance with Resolution 466/2012 of the National Health Counsel [18] and approved by the research ethics committee of the *Universidade Federal do Piauí* (n° 1.495.975). Informed consent was obtained from the parents of the participants or the responsible parties. For the study participants aged below 18 years, an informed consent was also obtained.

Anthropometry

Weight and height were measured based on the guidelines of Cameron [19] and Jelliffe &

Jelliffe [20]. A portable electronic scale (SECA®, model 803, Hamburg, Germany), with 100-g precision, was used to weigh the participants, and height was measured using a stadiometer (SECA®, Messband model 206, Hamburg, Germany), with 0.1-cm precision. Body Mass Index (BMI) was expressed in Z-scores and classified in accordance with guidelines of the World Health Organization. The following cut-off values were used: thinness percentile ≥ 0.1 and < 3 ; eutrophia percentile ≥ 3 and < 85 ; and obesity, percentile > 85 and ≤ 97 [21].

The technique of Callaway *et al.* [22] was utilized to measure Waist Circumference (WC) using an inelastic measuring tape (SECA®, model 201, Hamburg, Germany), with 0.1-cm precision. The measurements were compared using the curve of Fredriks *et al.* [23], utilizing the cut-off value for obesity (percentile ≥ 90). The Waist-To-Height *Ratio* (WHtR) was obtained by measuring the participants' WC and height. A cut-off value of 0.50 was utilized, which is the proposed limit to be used in the diagnosis of excessive abdominal fat in adolescents [24].

Assessment of alimentary consumption

The 24-hour alimentary record (R24H) was utilized to obtain data regarding alimentary consumption. In filling out the record, the multiple pass [25] method was utilized. The second R24H was utilized in 40% of the population, with a 2-month interval to correct for interpersonal variability [26]. The Nutwin software (version 1.6.0.7) of the Department of Information Science in Health of the *Universidade Federal de São Paulo* was utilized to calculate the quantities of Zn, Cu, and Se as well as vitamins A, C, and E.

Nutrients were adjusted for interpersonal variability using the Multiple Source Method (MSM) software version 1.0.1 (2011; the Department of Epidemiology of the German Institute for Human Nutrition, Potsdam-Rehbrücke, Nuthetal, Brandenburg, Germany), which estimates usual consumption [27].

Arterial pressure

Arterial Pressure (AP) was obtained in accordance with the guidelines of the 7th Brazilian Guidelines on Arterial Pressure [28] utilizing a calibrated aneroid sphygmomanometer (Model DS-44, Welch Allyn Tycos® Durashock, New York, United States of America), with appropriate arm cuff sizes for the adolescents' arm circumference. The means of the two measurements for Systolic Arterial Pressure (SAP) and Diastolic Arterial Pressure (DAP), obtained initially and after 5 minutes of rest, were calculated [29]. If the difference between the measurements of AP was greater than 5mmHg, two additional measurements were obtained, and their means were utilized for analysis [30]. The adolescents were classified as normotensive if the SAP and DAP were below the 90th percentile for their height that is relative to sex and age [28].

Biochemical profile

Blood sample (5mL) was collected by nurses on school premises after fasting for 12h. To determine serum lipid levels, the samples were cooled in a tube without anticoagulants. The levels of HDL-C, Total Cholesterol (TC), Triglycerides (TG), and blood glucose were obtained using the colorimetric enzymatic method (ModeloBioSystems 310, Curitiba, Paraná, Brazil) along with the Labtest® kits. The Friedwald [31] formula was utilized to calculate LDL-C levels. The serum lipid measurements were classified in accordance with the Fifth Brazilian Guidelines on Dyslipidemia and Prevention of Atherosclerosis, and the reference values are as follows: TC level <170mg/dL; LDL-C level <110 mg/dL; HDL-C level >45mg/dL; and TG level <90mg/dL [2]. Glucose levels were classified in accordance with the criteria defined by the American Diabetes Association, and the reference value is <100mg/dL [32].

Cardiometabolic risk score

Cardiometabolic risk was classified in accordance with the cardiovascular risk factors,

expressed as continuous variables by the sum of the Z-scores for each factor that was evaluated [33]. Mean Arterial Pressure (MAP) was calculated in accordance with the MAP formula = $(\text{systolic AP} - \text{diastolic AP})/3 + \text{diastolic AP}$. The metabolic risk scores were obtained for the following variables: MAP, WC, and LDL-C, TC, TG, and glucose levels, using the formula $Z\text{-score} = [(\text{reading-mean}) / \text{SD}]$. For HDL-c levels, the scores were obtained using the inverse of the formula, considering that it is inversely related to cardiovascular risk. An individual with a Z-score ≥ 1 SD was at higher risk [34].

Statistical analysis

Data were analyzed using SPSS software (Statistical Package for Social Sciences, for Windows® version 22.0, SPSS Inc., Chicago, Illinois, United States). The chi-squared test was utilized to verify the association between the prevalence of high glucose levels and lipid alterations and cardiometabolic risk in terms of sex. The intake of antioxidant nutrients was expressed in tercile.

Bivariate analysis was conducted using an unadjusted Poisson regression. The post-stratification weights based on the type of school administration and the number of adolescents in the GRE of the respective school were considered. With the estimation of variance and the aim of calculating the Prevalence *Ratio* (PR) between the outcome variables (lipid alterations and cardiometabolic risk score) and the explanatory variables (antioxidant nutrients), the Poisson regression was used, with robust variance adjustment for both adjusted and non-adjusted analysis. In the analysis, sex was utilized as a possible interacting variable. Variables with a *p*-value <0.20 in the unadjusted analysis were used in the multivariate analysis, and to control possible confounding factors, sex, age, mother's schooling, and type of school were adjusted. A *p*-value <0.05 was considered statistically significant.

RESULTS

Of the 348 participants, 21 were excluded, of which 11 refused and others had hemolysis of blood samples. Thus, the final sample consisted of 327 adolescents. Table 1 shows the data on the significant prevalence of glycemic alterations as well as the increased consumption of Zn, Cu, and vitamin A in boys. However, the TC level, cardiometabolic risk, and intake of vitamin E were significantly higher in girls than in boys.

All the independent variables used in the bivariate analysis in both sexes (Table 2) were included in the multivariate analysis ($p < 0.20$).

Table 3 presents the results of the analysis on the variables after adjustment. Results showed that the low intake of Zn was associated with high TC and TG levels in boys ($p < 0.05$). Moreover, an association was observed between low intake of vitamin A and high LDL-c and TC levels and cardiometabolic risk. Intake of vitamin C was associated with high LDL-c and TG levels. Furthermore, in girls, a significant association was observed between low intake of Zn and high LDL-c and TC levels and low HDL-c levels. Cu also was associated with high levels of TG and cardiometabolic risk. The low consumption of vitamin A was also considered a risk factor since it was associated with high TG levels. Furthermore, low intake of vitamin C was significantly associated with low HDL-c levels. Vitamin E was also associated with low HDL-c levels and increased cardiometabolic risk.

DISCUSSION

Changes in glucose and TC levels in girls were highly prevalent in this study. These results are in accordance with the findings of a study involving Brazilian adolescents, particularly girls [35]. However, the prevalence of high blood glucose levels was lower in the present study [36].

Regarding the association between the intake of antioxidant nutrients as well as lipid alterations and cardiometabolic risk, the high prevalence of these biochemical alterations was associated with the low consumption of these micronutrients (except for Se; data not presented in this study). These results show the effect of these antioxidants on the overall health of the population. It is not just a question on the lipid profile but also on the cardiometabolic risk, which was calculated considering anthropometric and biochemical risk factors.

Although the effects of Zn on the metabolism of lipoproteins are still controversial, studies have confirmed the effects of this mineral on the lipid profile of humans [37,38]. The associations between the low intake of Zn and low HDL-c levels and high TC and TG levels in boys as well as the LDL-c, TC, and HDL-c level in girls were validated in this study, showing that this nutrients cause lipid profile alterations. Kadhim *et al.* [39] have reported that the oral supplementation of Zn lowers LDL-c, TC, and TG levels in patients with diabetes.

Data show that Zn can act as an endogenous factor that protects an individual against atherosclerosis, inhibiting the oxidation of LDL-c by reactive oxygen species in the presence of transition metals. In addition, the appropriate alimentary consumption of Zn protects an individual against inflammatory diseases, such as atherosclerosis, by inhibiting the activation of transcription factors that are responsive to oxidative stress as well as the expression of inflammatory cytokines. This mineral can also partly block genes that codify inflammatory cytokines, such as interleukin-6 and interleukin-8, in the endothelial cells [39]. This result emphasized the importance of adequately consuming Zn as well as other micronutrients, such as Cu, which may be beneficial for the health.

Cu is a component of ceruloplasmin and Cu-Zn superoxide dismutase, which plays an important role in biochemical functions related to the enzymatic components of the antioxidant

Table 1. Prevalence of glucose and lipid levels, cardiometabolic risk, and the consumption of antioxidant nutrients in terms of sex. Teresina (PI), 2017.

Variables	Boys		Girls		95% CI	p-value
	n	%	n	%		
<i>Glucose level (mg/dL)</i>						
<100	93	28.4	174	53.3	1.79–5.75	0.00
≥100	38	11.6	22	6.7		
<i>Lipid profile (mg/dL)</i>						
LDL-c						
<110	66	20.2	98	30.0	0.65–1.60	0.92
≥110	64	19.8	93	28.4		
HDL-c						
≤45	59	18.0	88	27.0	0.65–1.59	0.94
>45	73	22.3	107	32.7		
TC						
<170	66	20.2	77	23.5	0.40–0.98	0.04
≥170	65	19.9	119	36.4		
TG						
≥90	25	7.6	32	9.8	0.67–2.13	0.55
<90	106	32.4	162	49.5		
<i>Cardiometabolic risk</i>						
Low	30	9.2	15	4.6	1.81–6.87	0.00
High	102	31.2	180	55.0		
<i>Food consumption or Dietary intake</i>						
Zinc						
1st tercile	38	11.6	86	26.3		0.00
2nd tercile	41	12.5	72	22.1		
3rd tercile	53	16.2	37	11.3		
Copper						
1st tercile	12	3.7	115	35.2		0.00
2nd tercile	38	11.6	75	22.9		
3rd tercile	82	25.1				
Vitamin A						
1st tercile	36	11.0	71	21.7		0.02
2nd tercile	47	14.4	72	22.0		
3rd tercile	41	12.5	36	11.0		
Vitamin C						
1st tercile	71	21.7	39	12.0		0.00
2nd tercile	26	8.0	85	25.9		
3rd tercile	35	10.7	71	21.7		
Vitamin E						
1st tercile	43	13.1	66	20.2		0.60
2nd tercile	63	19.3	101	30.8		
3rd tercile	25	7.6	29	9.0		

Note: N=327; LDL-C: Low-Density Lipoprotein; HDL-c: High-Density Lipoprotein; TC: Total Cholesterol; TG: Triglycerides. 95% CI: 95% Confidence Interval. Chi-squared test.

Table 2. Consumption of antioxidant nutrients and lipid alterations in terms of sex. *Teresina (PI)*, 2017.

Variables	LDL-C ≥100 mg/dL		HDL-C <45 mg/dL		TC ≥150 mg/dL		TG ≥100 mg/dL		High CR	
	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value
Boys										
<i>Zn</i>										
3rd tercile	1		1		1		1		1	
2nd tercile	0.98 (0.78-1.23)	0.86	1.09 (0.87-1.37)	0.43	1.12(0.92-1.38)	0.25	1.07 (0.97-1.17)	0.18	1.18 (0.98-1.42)	0.07
1st tercile	1.07 (0.86-1.33)	0.53	1.16 (0.94-1.42)	0.16	1.20(1.00-1.44)	0.04	1.17 (1.03-1.34)	0.01	1.09 (0.89-1.34)	0.42
<i>Cu</i>										
3rd tercile	1		1		1		1		1	
2nd tercile	1.12 (0.87-1.43)	0.39	1.14 (0.98-1.33)	0.09	1.12(0.88-1.41)	0.35	0.96 (0.79-1.16)	0.65	0.93 (0.76-1.14)	0.48
1st tercile	1.08 (0.85-1.36)	0.53	1.23 (1.04-1.45)	0.01	1.01(0.80-1.27)	0.93	1.02 (0.84-1.23)	0.84	1.00 (0.85-1.18)	0.99
<i>Vitamin A</i>										
3rd tercile	1		1		1		1		1	
2nd tercile	1.22 (1.02-1.46)	0.03	0.89 (0.74-1.08)	0.25	1.31 (1.12-1.54)	0.00	1.01 (0.90-1.14)	0.83	1.31 (1.09-1.56)	0.00
1st tercile	1.08 (0.89-1.33)	0.42	1.03 (0.88-1.21)	0.69	1.04 (0.84-1.28)	0.74	1.07 (0.97-1.18)	0.15	1.11 (0.91-1.35)	0.29
<i>Vitamin C</i>										
3rd tercile	1		1		1		1		1	
2nd tercile	1.15 (0.97-1.38)	0.11	1.06 (0.89-1.27)	0.49	1.11 (0.93-1.31)	0.24	1.25 (1.02-1.54)	0.03	0.96 (0.79-1.17)	0.68
1st tercile	1.23 (1.05-1.43)	0.01	1.00 (0.83-1.21)	0.97	1.14 (0.97-1.33)	0.11	1.02 (0.91-1.14)	0.71	1.08 (0.93-1.27)	0.31
<i>Vitamin E</i>										
3rd tercile	1		1		1		1		1	
2nd tercile	0.96 (0.79-1.15)	0.64	1.07 (0.87-1.32)	0.51	0.97 (0.80-1.17)	0.97	1.02 (0.82-1.27)	0.88	1.02 (0.82-1.27)	0.88
1st tercile	1.15 (0.91-1.44)	0.23	1.19 (0.94-1.52)	0.15	1.01 (0.79-1.29)	0.94	1.15 (0.88-1.52)	0.31	1.15 (0.88-1.52)	0.31

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Table 2. Consumption of antioxidant nutrients and lipid alterations in terms of sex. *Teresina* (PI), 2017.

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Variables	LDL-C ≥100 mg/dL		HDL-C <45 mg/dL		TC ≥150 mg/dL		TG ≥100 mg/dL		High CR	
	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value
Girls										
Zn										
3rd tercile	1		1		1		1		1	
2nd tercile	1.01 (0.89-1.15)	0.83	1.14 (0.98-1.33)	0.09	1.05 (0.95-1.17)	0.35	1.08 (0.97-1.21)	0.15	0.99 (0.96-1.04)	0.96
1st tercile	1.14 (1.03-1.26)	0.01	1.23 (1.04-1.45)	0.01	1.06 (1.00-1.22)	0.04	1.13 (0.96-1.34)	0.14	1.00 (0.97-1.04)	0.81
Cu										
3rd tercile	1		1		1		1		1	
2nd tercile	1.04 (0.95-1.16)	0.38	0.97 (0.84-1.11)	0.66	0.99 (0.87-1.12)	0.84	1.04 (0.92-1.18)	0.49	1.02 (0.97-1.08)	0.43
1st tercile	1.05 (0.82-1.34)	0.72	1.09 (0.85-1.41)	0.46	1.02 (0.73-1.42)	0.92	1.57 (1.23-2.00)	0.00	1.59 (1.17-2.16)	0.00
Vitamin A										
3rd tercile	1		1		1		1		1	
2nd tercile	1.05 (0.93-1.18)	0.42	1.03 (0.88-1.21)	0.21	1.01 (0.91-1.13)	0.82	1.13 (1.02-1.24)	0.01	1.03 (0.98-1.08)	0.22
1st tercile	1.03 (0.89-1.19)	0.71	1.15 (0.95-1.38)	0.15	1.05 (0.95-1.16)	0.36	1.14 (1.04-1.26)	0.00	1.04 (0.99-1.09)	0.09
Vitamin C										
3rd tercile	1		1		1		1		1	
2nd tercile	1.07 (0.92-1.24)	0.39	0.81 (0.68-0.96)	0.01	1.02 (0.90-1.14)	0.77	1.09 (0.98-1.21)	0.10	1.03 (0.97-1.11)	0.27
1st tercile	1.08 (0.93-1.27)	0.31	1.03 (0.87-1.23)	0.69	1.03 (0.91-1.17)	0.64	1.08 (0.95-1.21)	0.23	1.03 (0.96-1.10)	0.38
3rd tercile	1		1		1		1		1	
Vitamin E										
3rd tercile	1		1		1		1		1	
2nd tercile	1.00 (0.89-1.13)	0.98	1.09 (0.95-1.27)	0.22	1.02 (0.92-1.14)	0.68	1.03 (0.95-1.13)	0.46	0.94 (0.86-1.02)	0.15
1st tercile	1.09 (0.97-1.24)	0.15	1.24 (1.04-1.49)	0.01	1.12 (1.02-1.23)	0.02	1.07 (0.99-1.16)	0.07	1.00 (0.89-1.12)	0.99

Note: N=327; LDL-C: Low-Density Lipoprotein-cholesterol; HDL-c: High-Density Lipoprotein-cholesterol; TC: Total Cholesterol; TG: Triglycerides. Adjustment variables: PR, Prevalence Ratio; 95% CI, 95% Confidence Interval.

Table 3. Adjusted prevalence ratio between antioxidant nutrients and lipid alterations in terms of sex (n=327). *Teresina (PI), 2017.*

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Variables	LDL-C ≥100 mg/dL		HDL-C <45 mg/dL		TC level ≥150 mg/dL		TG level ≥100 mg/dL		High CR	
	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value
Boys										
Zn										
3rd tercile	-		1		1		1		1	
2nd tercile	-		1.09 (0.87-1.38)	0.42	1.15 (0.96-1.38)	0.13	1.08 (0.98-1.17)	0.10	1.18 (0.98-1.42)	0.07
1st tercile	-		1.15 (0.93-1.42)	0.19	1.22 (1.04-1.44)	0.01	1.19 (1.06-1.35)	0.00	1.09 (0.88-1.34)	0.42
Cu										
3rd tercile	-		1		-		-		-	
2nd tercile	-		0.94 (0.73-1.21)	0.94	-		-		-	
1st tercile	-		1.09 (0.87-1.35)	1.09	-		-		-	
Vitamin A										
3rd tercile	1		-		1		1		1	
2nd tercile	1.21 (1.03-1.42)	0.02	-		1.31 (1.13-1.53)	0.00	1.01 (0.89-1.15)	0.82	1.34 (1.13-1.60)	0.00
1st tercile	1.06 (0.87-1.28)	0.58	-		1.02 (0.83-1.24)	0.87	1.07 (0.95-1.21)	0.29	1.15 (0.94-1.40)	0.18
Vitamin C										
3rd tercile	1		-		1		1		-	
2nd tercile	1.15 (0.96-1.37)	0.12	-		1.10 (0.93-1.31)	0.27	1.25 (1.02-1.53)	0.03	-	
1st tercile	1.19 (1.00-1.41)	0.04	-		1.10 (0.93-1.30)	0.27	1.08 (0.97-1.21)	0.15	-	
Vitamin E										
3rd tercile	-		1		-		1		1	
2nd tercile	-		1.08 (0.88-1.33)	0.46	-		1.07 (0.96-1.19)	0.21	1.02 (0.81-1.27)	0.88
1st tercile	-		1.18 (0.93-1.51)	0.16	-		1.05 (0.87-1.27)	0.59	1.15 (0.89-1.48)	0.29

Table 3. Adjusted prevalence ratio between antioxidant nutrients and lipid alterations in terms of sex (n=327). *Teresina (PI), 2017.*

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Variables	LDL-C ≥100 mg/dL		HDL-C <45 mg/dL		TC level ≥150 mg/dL		TG level ≥100 mg/dL		High CR	
	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value	PR (95% CI)	p-value
Sex										
Girls										
Zn										
3rd tercile	1		1		1		1		-	
2nd tercile	1.02 (0.91-1.13)	0.77	1.13 (0.98-1.31)	0.08	1.04 (0.95-1.15)	0.35	1.02 (0.96-1.21)	0.20	-	
1st tercile	1.12 (1.02-1.22)	0.02	1.25 (1.06-1.48)	0.01	1.08 (0.99-1.18)	0.07	1.14 (0.98-1.32)	0.09	-	
Cu										
3rd tercile							1		1	
2nd tercile							1.05 (0.93-1.19)	0.39	1.02 (0.97-1.08)	0.45
1st tercile							1.64 (1.21-2.21)	0.00	1.59 (1.14-2.22)	0.01
Vitamin A										
3rd tercile			1				1		1	
2nd tercile			1.02 (0.87-1.18)	0.82			1.13 (1.03-1.25)	0.01	1.03 (0.98-1.08)	0.19
1st tercile			1.16 (0.95-1.42)	0.15			1.14 (1.04-1.25)	0.00	1.04 (0.99-1.09)	0.10
Vitamin C										
3rd tercile	1		1						-	
2nd tercile	1.04 (0.90-1.20)	0.56	0.82 (0.69-0.97)	0.02			1.08 (0.97-1.21)	0.16	-	
1st tercile	1.08 (0.93-1.24)	0.30	1.03 (0.86-1.23)	0.74			1.08 (0.96-1.22)	0.19	-	
Vitamin E										
3rd tercile	1		1		1		1		1	
2nd tercile	1.01 (0.90-1.12)	0.92	1.08 (0.95-1.24)	0.23	1.02 (0.92-1.13)	0.73	1.04 (0.95-1.13)	0.39	0.94 (0.86-1.02)	0.12
1st tercile	1.07 (0.95-1.21)	0.24	1.29 (1.07-1.56)	0.01	1.09 (1.00-1.21)	0.05	1.07 (0.98-1.17)	0.12	1.02 (0.91-1.14)	0.74

Note: N=327; LDL-C: Low-Density Lipoprotein-cholesterol; HDL-c: High-Density Lipoprotein-cholesterol; TC: Total Cholesterol; TG: Triglycerides. Adjustment variables: PR; Prevalence Ratio; 95% CI: Confidence Interval 95%.

defense system. Therefore, increased susceptibility to oxidative damage can be one of the biological consequences that contribute to pathological Cu deficiency, along with hypercholesterolemia, and predisposition to CVD [40]. The results of this study indicate the associations between low intake of Cu as well as high TC level and cardiometabolic risk, which are the risk factors in women. These data remain controversial because the study by Suarez-Ortegón *et al.* [7] did not show an association between the consumption of Cu as well as lipid levels and metabolic syndrome in adolescents.

Regarding the consumption of vitamins in boys, associations were observed between low intake of vitamin A and elevated LDL-c and TC levels and cardiometabolic risk. In girls, low intake of vitamin A was associated with high TG levels. Low intake of vitamin E was associated with lower HDL-c levels and high TC levels. Another study has shown that the concentrations of vitamins A and E were positively correlated with the levels of TG, TC, and LDL-c in children [8]. Retinol binding-protein was also associated with high lipid levels, particularly TG levels, in children in Switzerland [41]. These results may be explained by the roles of vitamins A and E in lipid metabolism. Vitamin A is associated with lipid metabolism via the retinaldehyde dehydrogenase enzyme 1, whereas vitamin E is involved in this process mainly because it protects the lipids from oxidation and prevents oxidative damage. Thus, high lipid levels will require a high intake of vitamins A and E [42].

A meta-analysis of randomized trials has shown that supplementation with vitamin C significantly reduced LDL-c levels in healthy participants. However, it did not positively affect HDL levels [43]. These results are in accordance with those of the present study in which a decreased intake of vitamin C was associated with elevated LDL-c and TG levels among boys. However, low intake of vitamin C was also associated with low HDL-c levels in girls.

The benefits of vitamin C can be explained by the fact that this vitamin is a cofactor of

enzyme 7- α -hydroxylase, which is the rate limiting enzyme in the synthesis of bile acid [44]. In the liver, the conversion of cholesterol into bile acids can increase the expression of LDL-c receptors in the hepatocytes [45]. This will lead to greater capture of LDL-c in the circulation and lower its concentrations in the blood. Since vitamin C facilitates the conversion of cholesterol into bile acids, this can help reduce cholesterol concentration in the blood [46]. Another possible mechanism involves the role of vitamin C as an antioxidant. By inhibiting the oxidation of LDL-c, vitamin C facilitates its binding and absorption with the help of the LDL-c receptors in the hepatocytes [44].

Micronutrient deficiencies are mainly caused by an unhealthy diet [47]. Food is consumed without taking into consideration its nutrient content. This fact is known and exploited by businesses and the food industry, which offer increasingly practical, palatable, durable, and more attractive food to the general population. Processed foods, which are poor in antioxidant nutrients (Zn, Cu, and vitamins A, C, and E), are more accessible to all age groups, and the increased consumption of these products is considered one of the factors contributing to the increased prevalence of obesity and chronic diseases [48].

This study has some limitations. This is a cross-sectional study, which limits the findings to the level of association. Certain problems have been identified from the diet diaries of the adolescents (records). This may have been a problem in the two R24H that were utilized to estimate alimentary consumption. The variance ratio for the intake of nutrients in this population was twice as great as that in adults, partly due to over or low reporting of ingestion [49]. Therefore, to reduce these errors, the nutrients were corrected in accordance with interpersonal variability.

Considering the importance of these antioxidant nutrients on lipid metabolism and cardiometabolic risk, food and nutritional

education activities should be initiated, which are in accordance with the food guidelines that emphasize the adoption of food standards based on *in natura* or minimally processed foods to reduce and prevent non-communicable diseases. The increased consumption of foods rich in substances that fight against oxidative stress is important, not merely the intake of antioxidants in isolation or in supplemental form because the dose and duration of supplementation of each individual micronutrient remains controversial.

CONCLUSION

Associations between the intake of antioxidant nutrients (Zn, Cu, and vitamins A, C, and E) as well as lipid alterations and cardiometabolic risk were observed in the present study. The presence of these associations indicates the need for interventions in the younger population, with emphasis on consuming nutrient-rich foods that improve the health profile of adolescents.

CONTRIBUTORS

LM NASCIMENTO participated in the design of research and data collection, performed biochemical and statistical analyzes, interpreted the results and wrote the article; KRO GOMES participated in the conception of the study, of the sample design and revised the article; MDM MASCARENHAS, CES MIRANDA, and TME ARAÚJO participated in the study design and reviewed the article; KMG FROTA participated in the design of the research, conducted the biochemical and statistical analyzes and reviewed the article. All authors approved the final version of the manuscript.

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