



Nutrition during the early life cycle

Dietary patterns in middle childhood and behavior problems in adolescence

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Abstract

Background/objectives Adherence to a “Western” style dietary pattern has been related to behavior problems in children in high-income countries; however, dietary patterns may differ in countries undergoing the nutrition transition. Associations of dietary patterns with behavior problems in a Latin American context have not been evaluated.

Subjects/Methods Mothers of 385 children 5 to 12 y old completed a food frequency questionnaire (FFQ) on the children’s usual intake at enrollment into a cohort study. Four dietary patterns were identified through principal component analysis of the FFQ: animal protein, snacking, cheaper protein, and traditional/starch. After a median 6 y follow-up, adolescents reported behavior problems via the Youth Self Report, a standardized questionnaire. We compared the continuous distributions of externalizing and internalizing behavior problems and their subscales across quartiles of adherence to the four dietary patterns using multivariable linear regression.

Results Boys in the highest quartile of adherence to the animal protein pattern in middle childhood had an adjusted 5.5 units lower (95% CI $-9.5, -1.5$) mean total externalizing problems score compared with boys in the lowest quartile (P trend = 0.008). Adherence to the animal protein pattern was also inversely related to the aggressive behavior externalizing subscale in a dose–response manner among boys (P trend = 0.009). There were no associations between adherence to other dietary patterns and externalizing problems in boys or girls. There were no associations with internalizing problems.

Conclusion Adherence to an animal protein dietary pattern in middle childhood was associated with less externalizing behavior problems in adolescent boys.

Introduction

At least one in ten adolescents has a mental health-related problem [1], including externalizing (e.g., conduct disorder)

or internalizing (e.g., depression or anxiety) disorders. Childhood diagnoses of these disorders often tract into adulthood [2]. Externalizing and internalizing disorders are at the extreme of a spectrum of adolescent behavior problems that, even if not meeting clinical diagnosis criteria, are also associated with adverse physical [3] and mental [4] health outcomes in adulthood.

Previous cross-sectional and longitudinal studies in high-income countries have found positive associations between a “Western” style diet (i.e., a diet high in snack food, processed meats, and sweets) and behavior problems in childhood [5–19], but research in low and middle-income countries (LMIC) is scant. Many LMIC are currently undergoing a “nutrition transition” marked by an increase in consumption of saturated fats, refined sugars, and highly processed foods [20] which coexists with diets characterized by lower intake of animal foods and fewer micronutrients [21]. Thus, dietary patterns among school-aged children likely differ between LMIC and high-income

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countries. Evaluating the relations between dietary patterns and behavior problems in LMIC may reveal novel associations.

To date, the association between dietary patterns and behavior problems has not been evaluated in a Latin American context. We therefore conducted a prospective study to investigate whether adherence to dietary patterns in middle childhood was related to behavior problems in adolescence using data from the Bogotá School Children Cohort (BoSCCo) study in Colombia, a country undergoing a rapid nutrition transition [22, 23]. We previously identified four dietary patterns in this population (animal protein, snacking, cheaper protein, and traditional/starch) [24]. Because iron deficiency (ID) and low plasma vitamin B-12 in middle childhood were associated with more externalizing behavior problems in BoSCCo boys [25] and these micronutrients are found in highly bioavailable form in animal foods, we hypothesized that adherence to the animal protein pattern was inversely associated with behavioral problems in boys. We also hypothesized that adherence to the snacking pattern was positively associated with behavioral problems, in line with results from high-income countries [5–19].

Methods

Study design and population

Details on the BoSCCo study design have been previously reported [25, 26]. Briefly, we recruited 3202 randomly selected children aged 5–12 y from primary public schools in February 2006. Since the majority of children who attend public schools in Bogotá are from low- and middle-income families, our sample pertains to these groups.

Baseline information

At the time of enrollment, we collected information on child, parental, and household characteristics with the use of a parental self-administered survey. The questionnaire inquired about the child's usual weekly time spent watching television/playing video games, maternal education, height and weight, number of people regularly sleeping in the household, household food insecurity, total monthly income, number of household assets, and socioeconomic status (SES). Household food insecurity was assessed with a validated Spanish language version of the USDA Household Food Security Survey module [27, 28]. Number of household assets was determined from a list that included refrigerator, bicycle, blender, television, stereo, and washing machine. Household SES was determined per the city government's classification of neighborhoods for tax and public services pricing purposes.

During the weeks following enrollment, trained research assistants visited children at schools. At these visits, height was measured without shoes to the nearest 1 mm with wall-mounted portable Seca 202 stadiometers (Seca, Hanover, MD, USA), and weight was measured in light clothing to the nearest 0.1 kg with the use of Tanita H5301 electronic scales (Tanita, Arlington Heights, IL). Between May and June 2006, trained dietitians administered a 38-item food frequency questionnaire (FFQ) to a random sample of 1027 mothers to assess the children's usual food intake during the previous year. The FFQ was based on the most commonly consumed foods in this population as identified by the Colombian National Nutrition Survey 2005. All major sources of energy were included. The FFQ had nine frequency response options: 4–5 times per day, 2–3 times per day, once per day, 5–6 times per week, 2–4 times per week, once per week, 1–3 times per month, less than once per month, or never. Dietitians described a reference portion in natural units (e.g., one glass of milk or one egg) or standard measures for commonly consumed portions in this population and inquired about children's frequency of intake. We estimated energy intakes by multiplying the consumption frequency of each food by the energy contents of the specific portion using composition values from the USDA's Standard Reference food composition database, supplemented with data from manufacturers and published reports (Food Processor software; <http://www.usha.com>) as well as the Food Composition Table of Colombian Foods available from the Colombian Institute of Family Welfare [29]. In the subgroup that completed the FFQ, maternal height and weight were measured following the same methods described for the children.

Follow-up

From 2011 to 2015, we conducted an in-person follow-up assessment in a random sample of approximately one-third of cohort members ($n = 1139$), as previously described [25]. At this assessment, we ascertained youth behavior with the use of the Spanish-language version of the Youth Self Report (YSR), a self-administered questionnaire validated for use in youth aged 11–18 y [30]. The questionnaire consists of 112 statements on behaviors or feelings that youth rate as false, sometimes true, or often true. From the responses to these questions, we calculated age- and sex-standardized scores for behavior problem subscales (i.e., aggressive and rule-breaking behavior, anxious/depressed, withdrawn/depressed, somatic complaints, and attention, social, and thought problems) and two composite scales (total externalizing and total internalizing) using software provided by the test developer [31]. The aggressive and rule-breaking behavior subscales comprise the total externalizing problems scale, whereas the total internalizing problems scale is comprised of the anxious/depressed,

withdrawn/depressed, and somatic complaints subscales. The Spanish-language version of YSR has been widely used in other Latin American settings [32, 33].

The parents or primary caregivers of all children gave written informed consent prior to enrollment into the study and before the follow-up assessment. Youth gave written assent to participate. The study protocol was approved by the Ethics Committee of the National University of Colombia Medical School. The INSTITUTIONAL REVIEW BOARD AT The University of Michigan approved the use of data from the study.

Statistical analysis

In the subset with dietary information available at baseline, 385 adolescents aged 11–18 y completed the YSR and constituted the analytic sample. Primary outcomes were the continuous distributions of total externalizing and internalizing problems scores.

We used principal component analysis to identify dietary patterns using the responses to the 38 items in the FFQ as input, as described in detail elsewhere [24]. Four dietary patterns were identified based on eigenvalues > 1 , the Scree test, and interpretability. The patterns identified were animal protein (e.g., milk, yogurt, beef/pork/veal/lamb, cheese, chicken), snacking (e.g., candy, ice cream, packed fried snacks, soda, fruit punch), cheaper protein (e.g., cow tripe/liver, spleen, chicken giblets), and traditional/starch (e.g., rice, potato, plantain). Adherence to the animal protein pattern was related to plasma vitamin B-12 in a dose–response manner [24], which lends support to the validity of the FFQ.

We considered as covariates child, maternal, and household characteristics measured at baseline. SES covariates involved maternal height and underweight, food security, household income per person per day, number of household assets, and household SES classification. Child's body mass index (BMI)-for-age and height-for-age z scores were calculated according to the WHO growth reference for children and adolescents [34]. Maternal BMI was calculated as kg/m^2 from objectively measured height and weight in 76.6% of the mothers and from self-reported data in the rest.

Because previous findings on micronutrient status biomarkers and behavior in adolescence were restricted to boys [25], all analyses were conducted separately by sex. We first compared the continuous distribution of the adherence score to each of the four dietary patterns across categories of baseline child, maternal, and household characteristics using means \pm SD. For ordinal exposures, we conducted tests for linear trend by fitting a linear regression model with adherence to the dietary pattern as the outcome and a variable representing ordinal categories of each predictor introduced as a continuous covariate.

Because the associations with potential correlates and adherence to dietary patterns appeared similar among boys and girls, we then examined the adjusted associations of baseline child, maternal, and household characteristics with adherence to dietary patterns with the use of multivariable linear regression. Covariates were entered into the model per prior causal knowledge or if they were associated with the dietary pattern in bivariate analysis, and retained if they remained statistically significant at $P < 0.05$. Child sex and age were included in all models; child height and weight were not considered because they may be a consequence of adherence to a dietary pattern [35].

Next, we examined the distribution of behavior problem scores across quartiles of adherence to each dietary pattern with the use of means \pm standard deviation (SD). Tests for linear trend were conducted with the use of linear regression models with the behavior problem score as the continuous outcome and a variable representing quartiles of adherence to the dietary pattern as a continuous covariate. We then estimated mean differences and 95% confidence intervals (CIs) for behavior problem scores between quartiles of adherence to a dietary pattern using linear regression. If adherence to a dietary pattern was related to total externalizing or internalizing behavioral problems, we investigated whether adherence to that dietary pattern was related to the behavior problem subscales that comprise the composite score.

In multivariable analysis, we controlled for previously identified independent predictors of the child behavior outcomes [25], including SES [36, 37], and for correlates of exposures that were not their consequence. We guided the choice of confounders with use of causal diagrams (Supplementary Fig. S1). Child's age was included in all models as it was considered important from a mechanistic viewpoint. We deliberately avoided adjustment for total energy intake as it may be a consequence of adherence to a particular dietary pattern and thus constitute an intermediate variable. In supplemental analysis, we examined the relations of dietary patterns with attention, social, and thought problems in an analogous manner to that of total externalizing and internalizing problems. Empirical estimates of the variance were specified in all models to overcome potential deviations from the multivariate normality assumption. All P values are two-sided.

All analyses were conducted with the use of the Statistical Analyses System version 9.4 (SAS Institute Inc., Cary, NC, USA). Code is available upon request.

Results

Mean \pm SD age at baseline was 8.4 ± 1.6 y. Mean \pm SD age at the time of the follow-up assessment was 14.6 ± 1.7 y; 54.0% of children were female. Mean \pm SD total externalizing and

Table 1 Adjusted mean differences (95% CI)^a in adherence to dietary pattern scores by baseline characteristics in a cohort of school children in Bogotá, Colombia.

Characteristics	Animal protein	Snacking	Cheaper protein	Traditional/starch
Child's sex (male vs. female)	-0.07 (-0.28, 0.15)	0.22 (0.00, 0.44)	0.07 (-0.13, 0.27)	0.22 (0.00, 0.44)
Child's age at baseline, per 1 y	0.02 (-0.05, 0.08)	0.04 (-0.04, 0.12)	0.04 (-0.04, 0.12)	0.03 (-0.05, 0.10)
Mother's height, per 1 cm	0.02 (0.00, 0.03)			
Mother's BMI				
Per 1 kg/m ²				-0.03 (-0.05, -0.01)
<18.5 vs. ≥18.5 kg/m ²		-0.45 (-0.77, -0.13)		
Food insecurity, severe hunger vs. not	-0.42 (-0.70, -0.14)			
Income per person per day (Colombian Pesos) ^b				
Per 1000				-0.08 (-0.12, -0.04)
≥5000 vs. <5000			-0.22 (-0.40, -0.05)	
Household assets, per 1 ^c	0.10 (0.03, 0.17)			

^aFrom linear regression models for each pattern with adherence score as the outcome and adjustment covariates that included variables for which estimates are presented.

^bExchange rate at the time of the study: 1 USD = 2326 Colombian Pesos.

^cFrom a list including refrigerator, bicycle, blender, television, stereo, and washing machine.

internalizing problem scores were 51.9 ± 9.5 and 53.3 ± 9.8 among boys and 53.4 ± 9.5 and 54.2 ± 10.0 among girls, respectively.

In bivariate analyses among boys, adherence to the animal protein pattern was positively associated with mother's height and number of household assets, whereas adherence to the cheaper protein and traditional/starch patterns were inversely related to BMI-for-age Z score at baseline (Supplementary Table S1). Among girls, adherence to the animal protein and snacking patterns was inversely associated with household food insecurity (Supplementary Table S2). Adherence to the animal protein pattern was also related to daily income and number of household assets whereas adherence to the snacking pattern was additionally related to household SES. Adherence to the cheaper protein pattern was inversely associated with mother's education and height, income per person per day, and with household SES; while adherence to the traditional/starch pattern was inversely related to height- and BMI-for-age Z scores, mother's BMI, income per person per day, and household SES.

In multivariable analysis, maternal height and number of household assets were positively associated with adherence to the animal protein dietary pattern while food insecurity with severe hunger was inversely related to adherence to the animal protein pattern (Table 1). Male sex was positively associated with adherence to the snacking dietary pattern while maternal BMI < 18.5 kg/m² was inversely associated with adherence. Having an income of >5000 Colombian Pesos per person per day was inversely related to adherence to the cheaper protein pattern. Furthermore, maternal BMI and income per person per day were each inversely associated with adherence to the traditional/starch dietary pattern (Table 1).

Externalizing problems

Adherence to the animal protein pattern was inversely associated with total externalizing problems among boys (Table 2). After adjustment for child's baseline age, mother's height, household food insecurity, and number of household assets boys in the highest quartile of adherence to the animal protein pattern had an average 5.5 units lower total externalizing problem scores compared with boys in the lowest quartile (95% CI -9.5, -1.5; *P* trend = 0.008) (Table 2). Adherence to other dietary patterns was not associated with total externalizing problems among boys or girls in bivariate or multivariable analysis (Table 2). We further examined the associations of adherence to the animal protein pattern with the subscales of externalizing problems in boys. The mean aggressive behavior score was an adjusted 4.2 units lower (95% CI 1.3, 7.1; *P* trend = 0.009) among boys in the highest versus the lowest quartile of adherence. There were no statistically significant associations with rule-breaking behavior scores (Table 3).

Internalizing problems

Dietary pattern adherence was not related to total internalizing problem scores among boys or girls in bivariate or multivariable analysis (Table 4).

Attention, social, and thought problems

In bivariate analysis, adherence to the traditional/starch pattern was related to attention problems among girls (Supplementary Table 3). After adjustment for child's

Table 2 Total externalizing problem scores at 11–18 y of age according to quartiles of adherence to dietary patterns in middle childhood among children from Bogota, Colombia.

Behavior problem score	Quartile of adherence				<i>p</i> ^a
	Q1 Boys <i>n</i> = 44 Girls <i>n</i> = 52	Q2 Boys <i>n</i> = 44 Girls <i>n</i> = 52	Q3 Boys <i>n</i> = 45 Girls <i>n</i> = 52	Q4 Boys <i>n</i> = 44 Girls <i>n</i> = 52	
Animal protein					
Boys					
Mean ± SD	53.9 ± 9.3	52.4 ± 7.9	51.6 ± 11.1	49.5 ± 9.1	0.02
Adjusted difference ^b	Reference	-2.3 (-6.1, 1.6)	-3.0 (-7.4, 1.5)	-5.5 (-9.5, -1.5)	0.008
Girls					
Mean ± SD	53.5 ± 9.3	52.6 ± 9.1	52.6 ± 10.4	55.0 ± 9.4	0.43
Adjusted difference	Reference	-0.1 (-3.7, 3.4)	0.0 (-3.5, 3.6)	2.2 (-1.4, 5.7)	0.24
Snacking					
Boys					
Mean ± SD	52.8 ± 8.1	53.5 ± 10.3	49.9 ± 9.0	51.3 ± 10.3	0.18
Adjusted difference	Reference	0.6 (-3.3, 4.5)	-3.0 (-6.6, 0.6)	-1.8 (-5.8, 2.1)	0.14
Girls					
Mean ± SD	54.4 ± 8.9	54.4 ± 10.3	52.1 ± 9.3	52.8 ± 9.7	0.21
Adjusted difference	Reference	0.1 (-3.6, 3.7)	-2.2 (-5.6, 1.2)	-1.9 (-5.4, 1.6)	0.16
Cheaper protein					
Boys					
Mean ± SD	51.3 ± 9.3	49.6 ± 8.8	53.6 ± 9.5	52.9 ± 10.1	0.17
Adjusted difference	Reference	-1.4 (-5, 2.3)	2.1 (-2.2, 6.4)	2.5 (-1.6, 6.6)	0.10
Girls					
Mean ± SD	53.0 ± 10.2	54.6 ± 9.0	52.8 ± 9.6	53.2 ± 9.4	0.84
Adjusted difference	Reference	0.2 (-3.7, 4.1)	-1.1 (-5.1, 2.8)	-1.3 (-5.3, 2.6)	0.39
Traditional/starch					
Boys					
Mean ± SD	52.0 ± 10.4	50.8 ± 7.1	53.0 ± 9.5	51.7 ± 10.6	0.83
Adjusted difference	Reference	-1.5 (-5.9, 2.8)	1.7 (-2.9, 6.4)	0.5 (-4.5, 5.5)	0.51
Girls					
Mean ± SD	53.6 ± 10.6	51.8 ± 9.9	54.0 ± 8.8	54.2 ± 8.8	0.51
Adjusted difference	Reference	-2.5 (-6.7, 1.6)	-0.7 (-4.6, 3.3)	-0.6 (-4.9, 3.6)	0.99

^aTest for linear trend when a variable representing quartiles of adherence to the dietary pattern was introduced into a linear regression model as a continuous covariate. Empirical estimates of the variance were specified in all models.

^bValues are mean differences and their 95% confidence intervals. All models are adjusted for child's age at baseline (continuous). The associations of adherence to the animal protein pattern and child behavior problems are additionally adjusted for mother's height (continuous), food insecurity with severe hunger (1 indicator), and number of household assets (continuous). Snacking dietary pattern models were additionally adjusted for mother's underweight (1 indicator for BMI < 18.5 kg/m²). Cheaper protein dietary pattern models were additionally adjusted for income per person per day (1 indicator for <5000 Colombian Pesos). Traditional/starch dietary pattern models were additionally adjusted for mother's BMI (continuous) and income per person per day (continuous).

age, maternal BMI, and income per person per day, girls in the highest quartile of adherence to the traditional/starch dietary pattern had a mean attention problem score 2.1 units higher than girls in the lowest quartile (95% CI 0.6, 3.6; *P* trend 0.004). Dietary pattern adherence was not related to social (Supplementary Table 4) or thought problems (Supplementary Table 5) in bivariate or multi-variable analysis in boys or girls.

Discussion

In this prospective study of low- and middle-income schoolchildren from Bogotá, Colombia, adherence to an animal protein dietary pattern in middle childhood was related to less total externalizing problems in adolescent boys, potentially due to less aggressive behavior. These associations were independent of baseline child, parental,

Table 3 Externalizing problems subscale scores at 11–18 y of age according to quartiles of adherence to the animal protein dietary pattern in middle childhood among boys from Bogota, Colombia.

Behavior problem score	Quartile of adherence				<i>p</i> ^a
	Q1 <i>n</i> = 44	Q2 <i>n</i> = 44	Q3 <i>n</i> = 45	Q4 <i>n</i> = 44	
Aggressive behavior					
Mean ± SD	57.5 ± 7.8	55.5 ± 6.4	55.9 ± 8.1	53.7 ± 5.5	0.02
Adjusted difference ^b	Reference	−2.5 (−5.5, 0.6)	−2.1 (−5.6, 1.3)	−4.2 (−7.1, −1.3)	0.009
Rule-breaking behavior					
Mean ± SD	54.5 ± 5.3	54.1 ± 4.4	54.5 ± 6.0	53.2 ± 4.3	0.25
Adjusted difference	Reference	−0.7 (−2.9, 1.4)	−0.3 (−2.8, 2.2)	−1.7 (−3.8, 0.4)	0.17

^aTest for linear trend when a variable representing quartiles of adherence to the dietary pattern was introduced into a linear regression model as a continuous covariate. Empirical estimates of the variance were specified in all models.

^bValues are mean differences and their 95% confidence intervals adjusted for child's age at baseline (continuous), mother's height (continuous), food insecurity with severe hunger (1 indicator), and number of household assets (continuous).

and household characteristics. Adherence to other dietary patterns in middle childhood was not related to total externalizing or internalizing behavioral problems in adolescence among boys or girls.

In this study, maternal height, food security, and number of household assets were each positively associated with adherence to an animal protein dietary pattern. This is consistent with results from studies in adults of low- to middle-income settings where indicators of higher SES are positively related to protein intake [38]. Adherence to the snacking dietary pattern was inversely related to maternal underweight, but not to other socioeconomic indicators. This contrasts with a previous finding that Colombian children's adherence to a snacking dietary pattern was related to household food security and wealth [39]. It is possible that correlates identified in Bogotá, a large urban center with relatively improved conditions, are not generalizable to the rest of the country. Finally, adherence to the cheaper protein and traditional/starch dietary patterns was inversely related to daily income per person; this could be because the foods comprising these patterns (e.g., animal viscera, rice, potatoes, plantains) are affordable to low-income families in this setting.

Prior studies of the association between adherence to an animal protein pattern or intake of animal foods and externalizing problems in childhood have been cross-sectional and their results varied across different settings. Among Korean preschool children, adherence to an animal protein dietary pattern was not associated with behavior problems [40]. However, another study of Korean school children aged 8–11 y found an inverse association between dairy intake and total externalizing problems, aggressive behavior, and rule-breaking behavior [41]. Among Chinese adolescents, adherence to an animal protein pattern was inversely associated with conduct problems [42]. In contrast, intake of meat and meat alternatives was positively

related to total externalizing problems among Australian adolescents at 14 years [14, 17]. Notably, interpretation of results from these cross-sectional studies is hampered by the possibility of reverse causation bias since behavior problems could lead to changes in diet.

The inverse association seen in our study between adherence to the animal protein pattern and externalizing behavior problems in boys may be partly explained through increased intake of micronutrients critical for neurobehavioral development that exist in animal foods in highly bioavailable form. Vitamin B-12 and iron could be particularly relevant as they have been related to mood [43] and child brain development [44], respectively. We previously found that low serostatus biomarkers of these micronutrients in middle childhood were related to externalizing behavior problems in boys from the same study population [25]. In addition, adherence to the animal protein pattern was strongly predictive of plasma vitamin B-12 concentrations in a dose-response manner [24], and measurement errors in dietary and biomarker assessments should be uncorrelated. Animal food intake could also affect behavioral development through increased intake of protein. In rodents, exposure to early postnatal protein deficiency alters hippocampal development [45, 46], increases vulnerability to oxidative stress in the cortex and cerebellum [47, 48], and disrupts the GABAergic and serotonergic neuronal systems [49]. In addition, early life protein deficiency results in more aggressive and socially abnormal behavior in monkeys [50] and rodents [51].

We did not find an association between adherence to the animal protein pattern and behavior problems among girls. The mechanisms that could explain sex differences in these relations are unclear. Nevertheless, the associations between biomarkers of micronutrients found in animal foods, including iron and vitamin B-12, and behavior outcomes in this cohort were also restricted to boys [25]. The

Table 4 Total internalizing problem scores at 11–18 y of age according to quartiles of adherence to dietary patterns in middle childhood among children from Bogota, Colombia.

Behavior problem score	Quartile of adherence				<i>P</i> ^a
	Q1 Boys <i>n</i> = 44 Girls <i>n</i> = 52	Q2 Boys <i>n</i> = 44 Girls <i>n</i> = 52	Q3 Boys <i>n</i> = 45 Girls <i>n</i> = 52	Q4 Boys <i>n</i> = 44 Girls <i>n</i> = 52	
Animal protein					
Boys					
Mean ± SD	52.8 ± 8.6	56.3 ± 8.8	52.3 ± 10.6	51.9 ± 10.6	0.31
Adjusted difference ^b	Reference	2.7 (−0.9, 6.4)	−1.5 (−5.5, 2.5)	−1.5 (−5.6, 2.5)	0.16
Girls					
Mean ± SD	53.8 ± 10.5	53.1 ± 10.6	54.5 ± 10.0	55.6 ± 9.1	0.26
Adjusted difference	Reference	−0.2 (−4.1, 3.8)	1.8 (−2.0, 5.6)	2.6 (−1.3, 6.4)	0.12
Snacking					
Boys					
Mean ± SD	52.9 ± 8.7	55.3 ± 9.0	53.7 ± 9.6	51.2 ± 11.4	0.31
Adjusted difference	Reference	2.1 (−1.6, 5.8)	0.6 (−3.2, 4.4)	−1.9 (−6.2, 2.4)	0.29
Girls					
Mean ± SD	53.7 ± 9.9	54.6 ± 11.1	54.8 ± 9.1	53.7 ± 10.3	0.97
Adjusted difference	Reference	0.8 (−3.1, 4.8)	1.3 (−2.3, 4.9)	−0.2 (−4, 3.5)	0.98
Cheaper protein					
Boys					
Mean ± SD	53.6 ± 10.4	52.8 ± 9.4	54.2 ± 10.0	52.6 ± 9.5	0.81
Adjusted difference	Reference	−1.6 (−5.9, 2.7)	−0.2 (−4.7, 4.3)	−0.9 (−5.2, 3.4)	0.85
Girls					
Mean ± SD	54.0 ± 9.4	56.0 ± 9.7	51.4 ± 9.5	55.5 ± 11.2	0.99
Adjusted difference	Reference	1.9 (−1.8, 5.6)	−2.5 (−6.4, 1.3)	0.5 (−3.7, 4.6)	0.62
Traditional/starch					
Boys					
Mean ± SD	54.3 ± 10.5	52.5 ± 8.9	52.5 ± 10.2	54.0 ± 9.6	0.88
Adjusted difference	Reference	−3.0 (−7.5, 1.5)	−2.7 (−7.3, 2.0)	−0.5 (−5.2, 4.2)	0.94
Girls					
Mean ± SD	54.3 ± 9.7	53.2 ± 10.7	54.7 ± 8.9	54.7 ± 10.9	0.66
Adjusted difference	Reference	−2.7 (−7.0, 1.7)	0.3 (−3.4, 3.9)	−2.1 (−6.5, 2.3)	0.66

^aTest for linear trend when a variable representing quartiles of adherence to the dietary pattern was introduced into a linear regression model as a continuous covariate. Empirical estimates of the variance were specified in all models.

^bValues are mean differences and their 95% confidence intervals. All models are adjusted for child's age at baseline (continuous). The associations of adherence to the animal protein pattern and child behavior problems are additionally adjusted for mother's height (continuous), food insecurity with severe hunger (1 indicator), and number of household assets (continuous). Snacking dietary pattern models were additionally adjusted for mother's underweight (1 indicator for BMI < 18.5 kg/m²). Cheaper protein dietary pattern models were additionally adjusted for income per person per day (1 indicator for <5000 Colombian Pesos). Traditional/starch dietary pattern models were additionally adjusted for mother's BMI (continuous) and income per person per day (continuous).

consistency of these findings lends support to the notion that a potential effect of animal food intake on behavior is due to increased micronutrient intake.

Adherence to other dietary patterns in middle childhood, including snacking, was not related to adolescent externalizing or internalizing behavior problems. This contrasts with previous studies conducted in high income countries which have found associations between adherence to a more

“Western” style diet, typically defined by frequent intake of high-fat and snack foods, and externalizing problems [5–19]. Studies in Korea and China also found associations between adherence to a sweet food or snacking dietary pattern and poorer social skills and anxiety/depression, respectively [40, 42, 52]. A potential reason for the lack of association between the snacking pattern and behavior problems in our study is limited variability in adherence to

snacking since the sample was restricted to low- and middle-income children and, in Colombia, snacking is most prevalent in children from higher SES families [39].

Finally, we found a positive association between adherence to the traditional/starch dietary pattern and attention problems in girls. Other studies have found associations between patterns that share some of the foods in the Colombian traditional/starch pattern (e.g., rice, potatoes, plantains) and attention problems. For example, in a cross-sectional analysis of Australian adolescents, adherence to a “Western” style diet whose loading factors included refined grains and potatoes were related to an ADHD diagnosis at age 14 y [53]. The nature of these associations warrants further research in other populations.

Our study has several strengths. Its longitudinal design reduces the possibility that the results are due to reverse causation. Although we lacked measurements of behavior at recruitment, these problems typically develop during adolescence and the YSR questionnaire is applicable only after age 11 y. In addition, the prospective collection of outcome data precludes recall bias. The YSR questionnaire has been validated for use in populations similar to ours [54]. The FFQ measures usual long-term intake, and there is indirect evidence of its validity to measure intake of animal foods in this population [24]. Finally, we were able to control for relevant potential confounders of the association between adherence to an animal protein dietary pattern in middle childhood and behavior problems in adolescence.

There are limitations as well. Diet was assessed in middle childhood only. If diet at this age was correlated with diet earlier or later in development, then our results may reflect the potential effect of the exposure at a different time point rather than exposure during middle childhood. In addition, maternal reports of child’s diet may lead to misclassification of exposure. Specifically, mothers might underreport foods that children consume outside of the home. However, children’s intake of animal foods outside the family context is unlikely in this setting. We were not able to control for unmeasured independent predictors of the outcome that may be correlated with the exposure, such as parental mental health status. Thus, residual confounding cannot be ruled out. Finally, our results may not be generalizable to populations with different dietary patterns or to children from high-income families.

In conclusion, adherence to an animal protein dietary pattern in middle childhood was associated with decreased total externalizing problems and aggressive behavior among adolescent boys in Bogotá, Colombia. These associations are consistent with our previous finding that ID and low plasma vitamin B-12 in middle childhood were related to these outcomes. Adherence to the traditional/starch dietary pattern was related to attention problems among girls. Adherence to other dietary patterns in middle childhood

was not related to behavioral problems in adolescence. Additional longitudinal studies are warranted elsewhere in Latin America to examine whether this association replicates in comparable settings.

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Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

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