126 (2025) 202633

Contents lists available at ScienceDirect

Research in Autism

journal homepage: www.elsevier.com/locate/rasd

The relationship between dietary patterns and the autistic trait in school-age children

Sijia Zhou [a], Guo Zheng [b], Haoran Yu [a], Yulin Wu [a], Weilin Huang [b], Zheqing Zhang [a,*], Jingjing Liang [b,*]

[a] Department of Nutrition and Food Hygiene, Guangdong Provincial Key Laboratory of Tropical Disease Research, School of Public Health, Southern Medical University, Guangzhou 510080, Guangdong, China

[b] Guangzhou Women and Children's Medical Center, Guangzhou Medical University, Guangdong Provincial Clinical Research Center for Child Health, Guangzhou 510623, Guangdong, China

A R T I C L E I N F O

Keywords:
Autistic trait
Autism spectrum disorder
Dietary patterns
Food
School-aged children

A B S T R A C T

Objectives: Subclinical individuals with high autistic traits (ATs) exhibit milder but similar social and communicative impairments compared to those with autism spectrum disorder (ASD). This study investigated the relationship between dietary patterns (DPs) and the autistic trait (AT) in school-aged children in Guangzhou.

Methods: A cross-sectional study was conducted with 398 children aged six to nine. Principal component factor analysis identified dietary patterns, and ATs were assessed using the Autism Spectrum Quotient-Children's Version. Multiple linear regression, ANCOVA, and restricted cubic spline analysis were applied to examine associations.

Results: Children with higher AT had lower intake of light fruits and eggs (*P*: 0.008–0.043). An inverse association was found between the "vegetables-fruits-red meat" pattern and AQ-C scores (β: −0.708; 95 % *CI*: −1.366, −0.050). The "seafood-vegetables-fruits" pattern showed an inverted U-shaped association with AQ-C scores both in the overall sample and specifically among boys (*P* for non-linearity: 0.003–0.004).

Conclusions: Dietary patterns rich in fruits, vegetables, moderate red meat, seafood, and eggs may be associated with lower levels of autistic traits in school-age children, particularly in boys.

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder marked by persistent impairments in social interaction and communication, alongside restricted and repetitive patterns of behavior, interests, or activities(First, 2013). These symptoms typically emerge early in childhood and may include gastrointestinal issues, motor abnormalities, sleep disturbances, intellectual disabilities, and seizures, all of which significantly affect daily functioning(Rylaarsdam & Guemez-Gamboa, 2019). Epidemiological studies indicate that the prevalence of ASD has reached 1 in 31 children in the United States. Furthermore, ASD is diagnosed significantly more frequently in boys than in girls, with a male-to-female prevalence ratio of 3.4:1 (Shaw et al., 2025). Research indicates that not only individuals diagnosed with ASD but also some subclinical individuals with milder deficits in social and communication skills may exhibit varying degrees of autistic traits (ATs)(Page et al., 2016). ASD is often viewed as the extreme end of the distribution of autistic

* Corresponding authors.
E-mail addresses: zzqaa501@smu.edu.cn (Z. Zhang), stliangjingjing@126.com (J. Liang).

https://doi.org/10.1016/j.reia.2025.202633
Received 28 February 2025; Received in revised form 15 May 2025; Accepted 31 May 2025
Available online 10 June 2025

traits within the general population(Constantino, 2011; Westwood et al., 2016).

Although genetic factors are thought to account for only 10–20 % of ASD cases, the impact of environmental factors on ASD-related symptoms is increasingly recognized, with nutritional factors playing a crucial role in the development of ASD(Karhu et al., 2020; Masini et al., 2020). Investigation into the relationship between dietary characteristics of children and autistic traits will provide key information for early intervention strategies aimed at improving symptoms.

Some studies have explored the effects of specific foods or nutrients on ASD, finding that children with ASD tend to consume fewer fruits and vegetables while obtaining excessive calories from energy-dense foods, including sugary beverages and other highly processed foods(Gray et al., 2024). A meta-analysis has shown that children with ASD tend to have lower intakes of protein, calcium, phosphorus, selenium, vitamin D, thiamine, riboflavin, and vitamin B12. These nutrient deficiencies may adversely affect neurological function, subsequently impacting cognitive, emotional, and behavioral regulation(Esteban-Figuerola et al., 2019). Internationally, many studies have explored the effects of specific foods or nutrients on ASD, such as gluten-free and casein-free diets, ketogenic diets, and specific carbohydrate diets(Kałużna-Czaplińska & Jóźwik-Pruska, 2016;Cekici & Sanlier, 2019; Ristori et al., 2019; Hartman & Patel, 2020; Mandecka & Regulska-Ilow, 2022). These studies generally focus on specific foods or nutrients. Isolating the effects of individual nutrients or foods may present challenges, as these impacts are often minimal. Therefore, using a comprehensive and systematic dietary index might be more effective for investigating the influence of diet on autistic traits. This approach takes into account the diverse range of foods and nutrients consumed daily and the complex interactions between them.

Therefore, our study aims to further explore the food preferences and dietary traits of children with enhanced autistic traits, with the goal of providing more targeted intervention strategies to improve their dietary quality.

2. Materials and methods

2.1. Participants

This cross-sectional study was conducted in urban Guangzhou, China, between 2015 and 2017, focusing on healthy, typically developing children aged 6–9 years, as previously reported(Liang et al., 2020). A total of 398 children meeting the inclusion criteria were recruited through various methods, including invitation letters, advertisements, WeChat public accounts, and recommendation letters. The exclusion criteria were: (1) preterm births or twins; (2) a history of neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD), autism spectrum disorder (ASD), or Tourette syndrome; (3) a history of major organ diseases, including heart, lung, liver, or kidney disorders; (4) inherited metabolic disorders; and (5) incomplete data. Written informed consent was obtained from the parents or legal guardians of all participants before enrollment. The study was approved by the Ethics Committee of the School of Public Health at Sun Yat-sen University (No. 201549).

2.2. Data collection

Parents were interviewed to gather information on the demographic, socioeconomic, and lifestyle characteristics of the participants. Demographic data included age, gender, height, weight, parental education level, and household income. Anthropometric measurements, including body weight and height, were taken with children dressed in light clothing and barefoot. All measurements were conducted by trained technicians following a standardized protocol(Liang et al., 2020). Weight and height were measured to the nearest 0.1 kg and cm using a Tanita MC-780A scale (Tanita Corporation, Tokyo, Japan) and a portable fixed stadiometer (model TZG, China), respectively. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Lifestyle data included information on delivery mode, feeding practices, use of calcium and multivitamin supplements, and physical activity. Daily physical activity levels were assessed using a three-day physical activity questionnaire that covered two weekdays and one weekend day. Total physical activity was calculated by summing the metabolic equivalent scores (MET, kcal/kg/h) for each type of activity, multiplied by its daily duration (hours/day)(Ainsworth et al., 2011).

2.3. Assessment of the autistic trait in children

The children's autistic traits (ATs) were assessed using the Autism Spectrum Quotient: Children's Version (AQ-Child), revised by Bonnie Auyeung in 2008(Auyeung et al., 2008). This scale, designed for children aged 4 to 11, consists of five dimensions: social skills, attention switching, attention to detail, communication, and imagination. Parents were presented with 50 descriptive statements and asked to rate their level of agreement on a 4-point Likert scale (0 = 'definitely agree' to 3 = 'definitely disagree'). If five or fewer responses were missing, the AQ-Child score was adjusted for missing items using the following formula: total AQ-Child score + (mean item score × number of missing items)(Hoekstra et al., 2007). The maximum total score is 150 (with some items reverse-scored), where a higher score indicates more pronounced autism traits in the child. The AQ-C demonstrated good reliability in the sample population of this study, as evidenced by a Cronbach's α index of 0.731 and a validity index with a Pearson correlation coefficient of 0.612 ($P < 0.001$). This validity was reflected in the correlation between the AQ-C total scores and the total scores on the Chinese version of the Social Responsiveness Scale, as filled out by parents.

2.4. Assessment of dietary intake in children

The participants' average dietary intake over the past year was assessed using a 79-item food frequency questionnaire (FFQ). The reproducibility and validity of the FFQ have been previously documented(Amakye et al., 2018). Parents estimated the frequency of consumption (never, daily, weekly, monthly, yearly) for various foods. To assist in estimating portion sizes, photographs of food in standard portions were provided. The selected frequency and portion size for each food item were then used to calculate the average daily intake. Total daily energy intake was calculated using data from the 2009 China Food Composition Table (Yang & Wang, 2009)

2.5. Assessment of dietary patterns in children

Dietary patterns were identified using factor analysis of 21 food groups. First, the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of Sphericity were conducted. The KMO value was 0.631, and Bartlett's test of sphericity was significant ($P < 0.05$), indicating that factor analysis was suitable for this data set. Factors were rotated using varimax rotation to maintain independence between factors while enhancing interpretability. The main factors (dietary patterns) were selected based on eigenvalues (>1.22), factor interpretability, the scree plot, and the proportion of variance explained by each factor. The dietary patterns were named according to the highest loadings (absolute values) of food groups for each factor. A factor score was calculated for each participant by summing the intake of each food group, weighted by its factor loading. A higher score indicated greater adherence to the respective dietary pattern.

2.6. Statistical analysis

Continuous variables are presented as means ± standard deviations, and comparisons among the three AT groups were analyzed using one-way ANOVA. Post hoc analysis for between-group differences was conducted using the LSD test. Categorical variables are presented as counts (percentages), and group differences were assessed using chi-square tests. The high and low AT groups were defined as the top and bottom 27% of total scores on the Autism Spectrum Quotient scale, while the middle portion represented the median AT group. This grouping was used as the main variable in the study.

Multiple linear regression analyses were conducted to estimate the association between AQ-C scores and dietary pattern scores among participants. Model 1 was adjusted for age and gender, while Model 2 included additional adjustments for height, weight,

Table 1
Baseline characteristics in participants divided by the autistic trait.

Variables	different autistic trait			
	Low (n = 108)	Median (n = 178)	High (n = 112)	P
Age (years)	8.15 ± 0.90	8.12 ± 0.95	8.03 ± 1.00	0.521
Gender, n (%)				**0.038**
Girls	54 (50.00)	74 (41.57)	37 (33.04)	
Boys	54(50.00)	104 (58.43)	75 (66.96)	
Height (cm)	130.48 ± 7.39	129.04 ± 8.03	127.95 ± 7.72	0.054
Weight (kg)	27.42 ± 6.74	27.24 ± 7.55	25.30 ± 6.33	**0.015**
BMI (kg/m^2)	15.96 ± 2.74	16.12 ± 2.93	15.30 ± 2.48	**0.045**
Delivery mode, n (%)				0.674
Vaginal	50 (46.30)	92 (51.69)	55 (49.11)	
Cesarean	58 (53.70)	86 (48.31)	57 (50.89)	
Feeding patterns, n (%)				0.852
Breastfeeding	91 (84.26)	154 (86.52)	95 (84.82)	
Artificial feeding	17 (15.74)	24 (13.48)	17 (15.18)	
Maternal education, n (%)				**0.004**
Secondary or less	27 (25.00)	69 (38.76)	56 (50.00)	
University	67 (62.04)	94 (52.81)	47 (41.96)	
Postgraduate or above	14 (12.96)	15 (8.43)	9 (8.04)	
Paternal education, n (%)				**0.001**
Secondary or less	33 (30.56)	66 (37.08)	59 (52.68)	
University	52 (48.15)	94 (52.81)	39 (34.82)	
Postgraduate or above	23 (21.30)	18 (10.11)	14 (12.50)	
Household income, n (%)				**0.006**
< 8000 Yuan/month	14 (12.96)	29 (16.29)	28 (25.00)	
8000 −15,000 Yuan/month	28 (25.93)	57 (32.02)	39 (34.82)	
> 15,000 Yuan/month	51 (47.22)	54 (30.34)	32 (28.57)	
No respond	15 (13.89)	38 (21.35)	13 (11.61)	
Use of calcium supplement, n (%)				0.133
Yes	49 (45.37)	64 (35.96)	52 (46.43)	
NO	59 (54.63)	114 (64.04)	60 (53.57)	
Use of multivitamin supplement, n (%)				0.539
Yes	23 (21.30)	30 (16.85)	18 (16.07)	
NO	85 (78.70)	148 (83.15)	94 (83.93)	
MET (Kcal/day/kg)	40.09 ± 3.95	39.71 ± 4.23	39.98 ± 4.56	0.740
The score of AQ-C	45.74 ± 5.79	59.56 ± 3.74	72.51 ± 5.39	**< 0.001**

Continuous data are shown as means ± SDs and categorical variables are presented as n (%); statistically significant p-values are indicated in bold. BMI: Body Mass Index; MET: Metabolic Equivalent Task calcium and multivitamin supplement use, MET, household income, and parental education. Analysis of covariance (ANCOVA) compared the covariate-adjusted AQ-C scores across quartiles of dietary pattern scores. To flexibly model the association between dietary patterns and AQ-C scores, a restricted cubic spline regression with three knots at the 25th, 50th, and 75th percentiles of dietary pattern scores was applied. Additionally, subgroup analyses were performed by gender to examine the association between dietary pattern scores and AQ-C scores within each gender group. All statistical analyses were performed using R software (v4.4.1) and IBM SPSS Statistics (v26, SPSS Inc., Chicago, IL, USA), with a significance level set at $P < 0.05$. All p-values were two-sided.

3. Result

3.1. Characteristics of participants

A total of 398 children (165 girls and 233 boys) were included in this study. The descriptive characteristics of the participants are presented in Table 1. The low AT group consisted of 108 children with a mean age of 8.15 ± 0.90 years, the middle AT group included 178 children with a mean age of 8.12 ± 0.95 years, and the high AT group had 112 children with a mean age of 8.03 ± 1.00 years. Significant differences were observed among the AT groups in terms of gender, weight, BMI, maternal education, paternal education, household income, and AQ-C scores (P:<0.001–0.045). However, no significant differences were found in age, height, delivery mode, feeding patterns, MET, or use of calcium and multivitamin supplements among the different AT groups ($P > 0.05$). Food intake in each group with different levels of autistic trait is shown in Table 2. Children in the high AT group had lower intakes of light fruits and eggs compared to those in the low AT group (P:0.008–0.043). Children in the median AT group had lower intakes of dark fruits and light fruits compared to those in the low AT group (P:0.001–0.011). No other significant associations were found between food intake and autistic traits.

3.2. Dietary patterns derived from dietary intake

Using the 21 food groups from the FFQ, we identified five predominant dietary patterns. The factor loading matrices are shown in Table 3. Dietary pattern 1, characterized by high factor loadings of fresh vegetables, fruits, and red meat, was termed the "vegetables-fruits-red meat" pattern. Dietary pattern 2, with high loadings for seafood, fresh vegetables, and fruits, was labeled the "seafood-vegetables-fruits" pattern. Dietary pattern 3 was defined by high loadings of mushrooms, nut, and soup beverage, and was named the "mushrooms-nut-soup beverage" pattern. Dietary pattern 4, characterized by high loadings of animal organs, eggs, and milk, was termed the "animal organs-eggs-milk" pattern. Lastly, dietary pattern 5, with high loadings of fish, refined cereals, and animal organs, was labeled the "fish-refined cereals- animal organs" pattern. Together, these five patterns explained 39.83% of the total variability.

3.3. Multiple linear regression of dietary pattern scores and AQ-C score

The multiple linear regression analysis examining the relationship between dietary patterns and autistic traits is shown in Table 4. In Model 1, the "vegetables-fruits-red meat" pattern was negatively associated with AQ-C scores (β: −0.910; 95% CI: −1.555, −0.264). This negative association remained in the fully adjusted model (β: −0.708; 95% CI: −1.366, −0.050). The "animal organs-eggs-milk"

Table 2
Food of participants by the autistic trait.

Food Groups (g/d)	different autistic trait			
	Low (n = 108)	Median (n = 178)	High (n = 112)	*P*
Refined cereals	97.68 ± 41.17	95.12 ± 38.72	102.01 ± 38.58	0.349
Whole grains	6.21 ± 7.22	6.02 ± 9.32	5.39 ± 9.56	0.769
Tuber crops	4.76 ± 5.24	4.16 ± 3.98	3.53 ± 3.19	0.216
Soybean	11.61 ± 13.59	10.87 ± 10.88	14.51 ± 29.33	0.256
Dark vegetables	119.69 ± 76.91	117.04 ± 83.36	96.79 ± 47.40	0.163
Light vegetables	52.20 ± 34.06	54.80 ± 55.93	43.70 ± 35.14	0.123
Preserved vegetables	0.54 ± 1.16	0.77 ± 2.11	0.85 ± 2.06	0.447
Mushrooms	13.10 ± 20.47	11.42 ± 18.30	11.43 ± 18.16	0.733
Dark fruits	78.12 ± 75.98	56.77 ± 56.06	71.94 ± 73.15	**0.023**
Light fruits	113.67 ± 85.66	79.84 ± 57.66	82.48 ± 65.43	**0.003**
Red meat	87.43 ± 55.48	86.00 ± 57.89	78.36 ± 51.57	0.409
Animal organs	3.82 ± 6.72	2.85 ± 4.51	3.93 ± 6.21	0.662
Marinated animal food	5.50 ± 8.39	4.69 ± 6.31	6.05 ± 10.06	0.841
Poultry	29.76 ± 42.05	28.94 ± 55.75	27.85 ± 39.72	0.957
Freshwater fish	8.67 ± 9.45	10.27 ± 15.40	8.93 ± 12.19	0.538
Sea fish	10.11 ± 14.39	11.66 ± 19.76	8.01 ± 14.19	0.204
Mollusks shellfish	12.34 ± 24.31	9.29 ± 9.08	9.02 ± 10.89	0.517
Eggs	36.55 ± 22.63	31.90 ± 21.47	30.51 ± 22.27	0.100
Milk	258.49 ± 166.96	235.54 ± 196.61	232.76 ± 184.44	0.514
Nut	8.75 ± 12.84	8.66 ± 16.06	7.36 ± 11.09	0.692
Soup beverage	103.07 ± 104.60	104.80 ± 98.50	104.98 ± 85.77	0.986

Table 3
Factor loading matrix of dietary patterns by principal component analysis with varimax rotation (n = 398) * .

Food Groups	dietary patterns				
	Vegetables-Fruits-Red meat	Seafood-Vegetables-Fruits	Mushrooms-Nut-Soup beverage	Animal organs-Eggs-Milk	Fish-Refined cereals-Animal organs
Refined cereals	0.360	-	−0.320	-	0.368
Whole grains	-	-	0.395	-	-
Tuber crops	0.255	−0.385	−0.211	-	−0.204
Soybean	0.222	-	-	-	-
Dark vegetables	**0.659**	**−0.451**	-	-	-
Light vegetables	**0.526**	**−0.560**	-	-	-
Preserved vegetables	-	-	-	0.346	0.339
Mushrooms	0.330	-	**0.518**	-	-
Dark fruits	**0.471**	0.393	-	-	-
Light fruits	**0.625**	-	0.204	−0.300	-
Red meat	**0.540**	-	−0.253	-	0.262
Animal organs	0.224	-	-	**0.583**	0.345
Marinated animal food	-	-	-	0.257	-
Poultry	-	0.245	-	-	-
Freshwater fish	0.371	-	-	0.239	−0.368
Sea fish	**0.406**	-	−0.243	-	**−0.612**
Mollusks shellfish	0.286	**0.534**	-	0.380	-
Eggs	0.288	-	-	**−0.493**	-
Milk	0.300	-	-	**−0.442**	0.289
Nut	0.277	-	**0.502**	-	-
Soup beverage	0.354	0.390	**−0.486**	-	-

*Factor loadings of < |0.20| are not listed in the table for simplicity. Loadings ≥ |0.40| are in bold.

pattern was positively associated with AQ-C scores (β: 0.963; 95% CI: 0.016, 1.910) in Model 1. After stratifying by gender in Model 1, the "vegetables-fruits-red meat" pattern was negatively associated with AQ-C scores in boys (β: −0.990; 95% CI: -1.812, −0.168), while the " animal organs-eggs-milk" pattern was positively associated with AQ-C scores in boys (β: −1.352; 95% CI: 0.131, 2.573). No other significant associations were observed between dietary patterns and autistic traits.

Table 4
Multiple linear regression analysis between dietary patterns and the autistic trait.

	Model1		Model2	
	β	*95% CI*	*β*	*95% CI*
	Vegetables-Fruits-Red meat			
Total	−0.910*	(−1.555, −0.264)	−0.708*	(−1.366, −0.050)
Girl	−0.763	(−1.818, 0.291)	−0.781	(−1.835, 0.274)
Boy	−0.990*	(-1.812, −0.168)	−0.795	(−1.664, 0.074)
	Seafood-Vegetables-Fruits			
Total	−0.326	(−1.201, 0.550)	−0.479	(−1.359, 0.401)
Girl	−0.477	(−1.767, 0.813)	−0.456	(−1.724, 0.812)
Boy	−0.291	(−1.482, 0.900)	−0.599	(−1.868, 0.670)
	Mushrooms-Nut-Soup beverage			
Total	−0.046	(−0.967, 0.876)	0.051	(−0.857, 0.958)
Girl	−0.735	(−2.023, 0.554)	−0.488	(−1.765, 0.788)
Boy	0.565	(−0.733, 1.863)	0.653	(−0.652, 1.959)
	Animal organs-Eggs-Milk			
Total	0.963*	(0.016, 1.910)	0.702	(−0.247, 1.652)
Girl	0.286	(−1.224, 1.796)	0.178	(−1.337, 1.692)
Boy	1.352*	(0.131, 2.573)	0.997	(−0.278, 2.272)
	Fish-Refined cereals-Animal organs			
Total	0.347	(−0.647, 1.342)	0.445	(−0.558, 1.449)
Girl	−0.495	(−2.018, 1.029)	−0.555	(−2.069, 0.959)
Boy	0.867	(−0.444, 2.179)	1.127	(−0.229, 2.484)

[*] $P < 0.05$, * * $P < 0.01$, * ** $P < 0.001$. Model 1: adjusted for age and gender. Model 2: adjusted for age, gender, height, weight, use of calcium supplement, use of multivitamin supplement, MET, maternal education, paternal education, household income.

3.4. Analysis of AQ-C score by dietary pattern score quartiles and restricted cubic spline regression

The associations between dietary patterns and AQ-C scores, analyzed using ANCOVA and restricted cubic spline regression, are shown in Fig. 1. After full adjustment for covariates, the percentage differences in the adjusted mean AQ-C scores between the first and fourth quartiles of the “vegetables-fruits-red meat” dietary pattern was −5.61% (*P* for trend: 0.035). In the “seafood-vegetables-fruit” pattern, children in the second quartile had significantly higher AQ-C scores than those in the first and fourth quartile ($P_{vsQ1} = 0.005$, $P_{vsQ4} = 0.011$). Gender-stratified analyses showed that boys in the fourth quartile of the “vegetables-fruits-red meat” pattern had significantly lower AQ-C scores than those in the first, second, and third quartiles ($P_{vsQ1} = 0.026$, $P_{vsQ2} = 0.001$, $P_{vsQ3} =0.028$). Boys in the second quartile of the “seafood-vegetables-fruits” pattern also had higher AQ-C scores than those in the first, third, and fourth quartiles (($P_{vsQ1} = 0.001$, $P_{vsQ3} = 0.050$, $P_{vsQ4} = 0.001$). No significant associations were observed for other dietary patterns.

Additionally, restricted cubic spline regression was used to explore non-linear associations between dietary patterns and AQ-C scores. An inverse U-shaped association was found between the “vegetables-fruits-red meat” pattern and AQ-C scores in boys (*P* for non-linearity: 0.031). A similar inverse U-shaped association was observed for the “seafood-vegetables-fruits” pattern, both in the overall sample and in boys specifically (*P* for non-linearity: 0.003–0.004). No significant associations were found for other dietary patterns.

4. Discussion

In our cross-sectional study, we identified five major dietary patterns among school-aged children in Guangzhou. We found that the "vegetables-fruits-red meat" pattern was negatively associated with AQ-C scores. Additionally, we observed an inverse U-shaped relationship between the "seafood-vegetables-fruits" pattern and AQ-C scores. Notably, in the gender-stratified analysis, such relationships were more pronounced in boys than in girls. However, no other significant associations were found between dietary patterns and autism traits.

Previous studies examining the impact of diets rich in vegetables, fruits, or meat on ASD have reported results consistent with this study. Studies (Malhi et al., 2017; Buro et al., 2021) reported that children with ASD consumed significantly fewer fruits and vegetables compared to typically developing children. Emond et al.’s cohort study(Emond et al., 2010)also found that at 54 months, children with ASD significantly reduced their daily intake of fruits and vegetables. Fruits and vegetables contain abundant antioxidants, such as vitamin A, vitamin C, carotenoids and polyphenols, which may help reduce ASD-specific symptom(Berding & Donovan, 2018). Additionally, fruits and vegetables are rich in serotonin, a key neurotransmitter involved in mood regulation, social behavior, and appetite, often referred to as the "happiness molecule". Gastrointestinal (GI) symptoms, such as constipation, are also commonly reported in children with ASD, and food selectivity may play a role in exacerbating these symptoms(Harris et al., 2021). Food selectivity, which we found to be associated with higher AQ-C scores, can limit the intake of fiber-rich foods like fruits and vegetables, potentially contributing to constipation(Li et al., 2023). This highlights the importance of addressing food selectivity not only for nutritional balance but also for alleviating GI symptoms in children with autistic traits. Vissoker et al. (2019) found that children with ASD consumed less meat than typically developing children. Meat is a high-quality protein source, crucial for brain development. Inadequate meat intake may lead to insufficient amino acids required for the growth, differentiation, and synapse formation of neurons. Iron and zinc, abundant in meat, are also essential for neurotransmitter synthesis. Deficiencies in these nutrients may result in altered serotonin and dopamine levels, with dopamine system abnormalities being linked to ASD symptoms(Naneix et al., 2021). Other studies have shown that diets rich in vegetables, fruits, and proteins may improve behavior and brain function in children with ASD, including attention, cognition, and emotional regulation(Matthews & Adams, 2023). Furthermore, research has indicated that high-fat, high-sugar, and animal-based diets contain phosphorus, sulfur, and chlorine, which metabolize into acidic compounds, while vegetables, fruits, and whole grains are rich in potassium, sodium, calcium, and magnesium, which metabolize into alkaline compounds. Children with high autistic traits tend to consume fewer vegetables, fruits, and whole grains, potentially leading to an acid-base imbalance that could negatively affect their health(Remer & Manz, 1995).

An inverse U-shaped association was observed between the "seafood-vegetables-fruits" pattern and AQ-C scores. Seafood is an excellent source of glutamate, the brain’s most abundant excitatory neurotransmitter. Moderate glutamate intake can enhance cognitive function and social skills, thereby lowering AQ-C scores and improving autism-related symptoms. However, excessive seafood consumption may lead to an overload of glutamate, resulting in neurotoxicity, disrupting the balance with γ-aminobutyric acid (GABA), and causing neural damage(Cho, 2013). This imbalance can impair cognitive and social abilities, leading to higher AQ-C scores. Moreover, insufficient vegetable consumption reduces antioxidant intake, which limits the body’s ability to neutralize free radicals, increasing oxidative stress and exacerbating brain damage. Therefore, it is recommended to moderate seafood intake while increasing vegetable consumption to balance glutamate levels and ensure an adequate supply of antioxidants. This dietary adjustment could help mitigate autism symptoms and improve overall cognitive and social functioning(El-Ansary & Al-Ayadhi, 2014).

Gender differences in sensitivity to dietary factors in relation to autism may be attributed primarily to genetic, hormonal, and metabolic factors. First, males have a higher genetic susceptibility to ASD, particularly due to gene mutations associated with the X chromosome, which significantly increase their risk of developing the condition(Pickles et al., 2020; Li et al., 2024). This genetic predisposition interacts with the effects of sex hormones, such as testosterone, on brain development, further amplifying the risk in males. Testosterone has profound effects on male brain development, making males more susceptible to external environmental factors, such as dietary patterns, while estrogen in females offers neuroprotective effects that mitigate these negative impacts(Bakker, 2022). Additionally, metabolic differences, particularly in how males process saturated fats and n-3 fatty acids, may make males more responsive to dietary patterns, which could influence neurodevelopmental outcomes(Mottron et al., 2015; Kemp et al., 2024). These

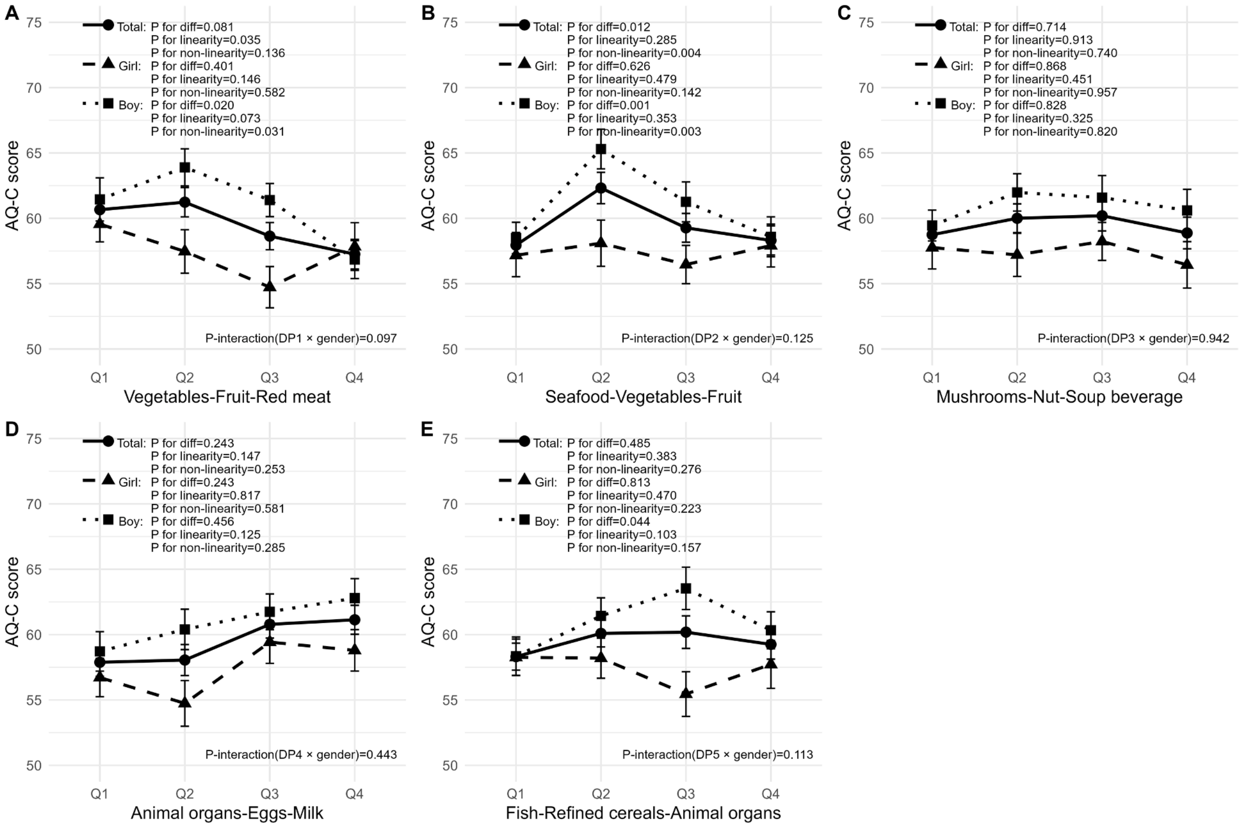

Fig. 1. Association between Dietary Patterns and AQ-C Scores analyzed by ANCOVA and Restricted Cubic Spline Regression. Covariates are adjusted for age, gender, height, weight, use of calcium supplement, use of multivitamin supplement, MET, maternal education, paternal education, household income. P for diff: p-value for between-group difference analyzed by ANCOVA.

genetic, hormonal, and metabolic factors collectively contribute to a heightened dietary sensitivity in males, helping to explain gender differences in the relationship between diet and autism traits.

The advantage of this study is that we used a dietary pattern approach to assess the relationship between dietary factors and autistic traits. This approach provides a more comprehensive understanding of overall dietary patterns and their potential impact, compared to traditional studies focusing on single nutrients or foods. Additionally, we explored the dietary habits of children with high autistic traits in the general population, contributing to the growing body of research on the link between autism and diet. However, our study has several limitations. First, the cross-sectional design precludes causal inferences regarding the relationship between diet and autistic traits. Additionally, the sample size of 398 children may lack sufficient statistical power to detect subtle associations. Furthermore, residual confounding from unmeasured or inaccurately measured variables could affect result accuracy. Notably, dietary patterns were identified using factor analysis of food frequency questionnaire data, and the sample consists solely of children from Guangzhou, China. These factors may limit our ability to fully capture cultural, regional, and individual variations and restrict the generalizability of our findings to other populations. Lastly, the absence of biological or biochemical markers limits our ability to explore underlying mechanisms. Additionally, our study did not include the 13-item Pervasive Developmental Problems (PDP) subscale, which could have provided further insights into autistic traits. Future research should incorporate nutritional biomarkers, physiological assessments, and cultural/regional factors to enhance understanding and validate findings.

5. Conclusion

Our findings suggested that diets rich in vegetables, fruits and red meat have a beneficial impact on reducing autistic traits in school-age children. Moreover, an inverse U-shaped relationship was observed between the "seafood-vegetables-fruit" dietary pattern and the autistic traits. A balanced intake of essential nutrients is crucial for children’s health, particularly for those exhibiting high levels of autistic traits. A well-structured diet supports healthy neurodevelopment and may reduce the risk of ASD. Future research should focus on longitudinal and interventional studies to deepen our understanding of these associations and confirm the role of specific dietary patterns in managing autistic traits. Additionally, future interventions should emphasize strategies such as gradually introducing new foods, creating a positive eating environment, and leveraging children’s interests and preferences to improve dietary habits and overall health.

Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the School of Public Health at Sun Yat-sen University (No. 201549).

Funding

This work received support from Natural Science Foundation of Guangdong Province, China (No. 2022A1515011161).

CRediT authorship contribution statement

Sijia Zhou: Writing – original draft, Methodology, Conceptualization, Investigation, Supervision. **Jingjing Liang:** Writing – review & editing, Supervision, Conceptualization, Funding acquisition, Methodology. **Zheqing Zhang:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization, Methodology. **Haoran Yu:** Investigation, Methodology, Project administration, Writing – original draft. **Guo Zheng:** Methodology, Conceptualization, Formal analysis, Investigation, Writing – original draft. **Weilin Huang:** Data curation, Formal analysis, Investigation, Project administration. **Yulin Wu:** Investigation, Methodology, Project administration, Writing – original draft.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

Acknowledgments

We want to thank all the children who participated, their parents, and every member of the research team who contributed to the data collection phase of this study.

Informed consent

Written informed consent was obtained from the parents or legal guardians of all participants before enrollment.

Consent for publication

Consent for publication was obtained from all authors.

Data availability

The data that has been used is confidential.

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