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Functional black bean-enriched chocolate cookies: a sensory-compatible nutritional strategy for children and adolescents with autism spectrum disorder

Abstract

Children and adolescents with Autism Spectrum Disorder (ASD) often exhibit feeding difficulties, such as food selectivity and sensory-related aversions, which can compromise their nutritional status and micronutrient intake. Innovative food strategies are needed to improve dietary quality and acceptance in this population. This study aimed to develop chocolate cookies with partial substitution of wheat flour by black bean flour (*Phaseolus vulgaris* L.) and evaluate their nutritional composition, iron content and in vitro bioaccessibility, as well as sensory acceptance by children and adolescents with ASD. Four formulations were prepared with 0%, 30%, 50%, and 70% substitution levels. Physicochemical analyses, iron quantification, and in vitro digestion assays were conducted. Sensory evaluation was performed by parents/guardians and by 15 autistic children and adolescents using a structured hedonic scale. The sample size corresponded to all eligible participants with ASD enrolled in specialized support institutions (APAE and CAPSj) in Ouro Preto and Mariana who consented to participate in the study, ensuring full inclusion of the accessible and willing population. The formulation with 70% black bean flour showed the highest protein and dietary fiber contents, along with a reduced energy value and lower saturated fat content compared to commercial cookies. The 30% substitution level presented the most favorable balance between total iron content and bioaccessible fraction. Sensory evaluation indicated good acceptance of the 30% and 50% formulations by the target group. Partial replacement of wheat flour with black bean flour in cookies is a promising strategy to enhance the nutritional quality and sensory adaptability of foods for individuals with ASD. The findings support the feasibility of incorporating such functional products into the diet of this population. Further longitudinal studies are warranted to assess long-term impacts on nutritional status and behavioral outcomes.

Keywords: autism spectrum disorder, food selectivity, functional foods, black bean flour, iron bioaccessibility, sensory acceptance, dietary intervention

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Introduction

Feeding behaviors in individuals with Autism Spectrum Disorder (ASD) are frequently characterized by selective eating patterns, often influenced by atypical sensory processing.[1] Such behaviors include strong preferences or aversions to specific textures, colors, or flavors, and may result in nutritionally inadequate diets with limited food variety.[2–5] Emerging evidence suggests a higher prevalence of micronutrient deficiencies in this population, particularly with respect to iron, zinc, and vitamin D, which may exacerbate symptoms such as fatigue, irritability, and attentional deficits.[6–8]

From a nutritional intervention perspective, the development of foods that are both sensorially acceptable and nutrient-dense represents a key strategy in addressing these dietary limitations.[9] Tailoring food products to align with the sensory preferences commonly observed in individuals with ASD can improve food acceptance and dietary compliance.[10,11] Cookies, as widely accepted and easy-to-consume products among children, offer a versatile platform for the incorporation of functional ingredients.[12,13]

Black beans (*Phaseolus vulgaris* L.) are a staple in the Brazilian diet and constitute a rich source of dietary fiber, plant-based protein, and micronutrients, including iron and zinc.[14,15] Prior studies have explored their incorporation into various baked goods, reporting favorable outcomes in both nutritional enhancement and consumer acceptance.[16,17] Nevertheless, black beans contain antinutritional factors such as phytates and tannins, which can hinder mineral bioavailability.[18] Therefore, assessments of *in vitro* iron bioaccessibility are essential for understanding the nutritional potential of such formulations.[19,20]

In parallel, the sensory characteristics of food, particularly texture, taste, and aroma, play a critical role in food acceptance among individuals with ASD.[21] Unfamiliar sensory stimuli can provoke adverse reactions or complete rejection of the food.[22,23] In this context, the involvement of caregivers in sensory evaluation protocols is essential, as it reflects the feasibility of introducing such foods into the home environment and daily dietary routines.[24,25]

This study aimed to develop chocolate cookies with partial substitution of wheat flour by black bean flour, evaluating their physicochemical properties, iron *in vitro* bioaccessibility, and sensory acceptance among children and adolescents with ASD. Moreover, the study contributes to broader public health and sustainability goals by promoting the inclusion of underutilized legumes in processed foods tailored to the needs of nutritionally vulnerable populations.

Materials and methods

The chocolate cookies were developed and analyzed at the Sensory Analysis Laboratory and the Starchy Products Pilot Plant of the School of Nutrition, Federal University of Ouro Preto (UFOP), Minas Gerais, Brazil.

Preparation of black bean flour

Black bean flour was prepared following the methodology described by Frota et al,[26] with minor modifications. Dry black beans were manually sorted to remove impurities such as stones and debris, then weighed and rinsed under running water. Beans were soaked in a 1:3 (w/v) bean-to-water ratio for 1 hour at room temperature. Post-soaking, they were oven-dried at 200 °C for 30 minutes (Wanke brand electric oven), then milled in an industrial blender (Skymsen Inox Copo Monobloco) for approximately 5 minutes to obtain a fine flour, which was subsequently sieved through a mesh size between 20 and 24.

Cookie formulation and production

Four cookie formulations were developed by partially replacing wheat flour with black bean flour at 0% (control), 30%, 50%, and 70% levels (Table 1), using a completely randomized design, following the method described by Clerici et al,[27] with adaptations. The flours were mixed with butter by hand until a crumbly texture was achieved. Eggs, sugar, baking powder, and vanilla extract were then incorporated, followed by manual mixing until a homogeneous dough was formed. Chocolate pieces were gently folded into the dough, which was portioned into 35 g units. The portions were refrigerated for at least 2 hours and baked in a preheated convection oven (Turbo Super Compacto, Progás) at 180 °C for approximately 25 minutes. Once cooled to room temperature (25 °C), the cookies were sealed in airtight containers and stored at room temperature until analyses.

Table 1 Formulations of chocolate cookies made with different concentrations of black bean flour

Ingredients (%)	Formulations (%)			
	0	30	50	70
Wheat flour	37.67	26.37	18.84	11.3
Black bean flour	-	11.3	18.84	26.4
Unsalted butter	10.46	10.46	10.46	10.5
Milk chocolate	15.7	15.7	15.7	15.7
Brown sugar	25.11	25.11	25.11	25.1
Eggs	10.46	10.46	10.46	10.5
Baking powder	0.31	0.31	0.31	0.31
Vanilla extract	0.29	0.29	0.29	0.29

Nutritional profiling

Nutritional composition was estimated based on the ingredients used, using data from the Brazilian Food Composition Table.[28] Calculations were standardized to a 40 g serving size. The values obtained were compared with a widely available commercial chocolate cookie to identify significant differences in macronutrients, energy value, fiber, and mineral content.

Physicochemical analyses

Color analysis was performed in triplicate using a Konica Minolta CR-400 colorimeter under standardized D65 lighting conditions, as described by.[29] Results were expressed using the CIELab color space: L* (lightness, 0 = black, 100 = white), C* (chroma/saturation), and h° (hue, 0° = red, 360° = blue).

Total iron content was determined using the official methods of the Instituto Adolfo Lutz.[30] The *in vitro* bioaccessible iron fraction was quantified following the gastrointestinal simulation method by Silva and Cadore.[31] Briefly, 5 g of each sample underwent simulated salivary digestion with amylase, followed by gastric digestion with pepsin in acidic saline, and then intestinal digestion with bile salts and pancreatin. Each phase was incubated at 37 °C with orbital shaking (10 minutes for salivary, 2 hours each for gastric and intestinal phases). After digestion, samples were cooled in an ice bath to deactivate enzymes and centrifuged to obtain the supernatant. This bioaccessible fraction was analyzed using Flame Atomic Absorption Spectrometry (FAAS).

Assessment of food selectivity and sensory acceptance

The study was approved by the Ethics Committee of the Federal University of Ouro Preto (approval number: 5.806.646) and was conducted in three stages.

Fifteen children and adolescents with a clinical diagnosis of ASD and their legal guardians participated in the study, residing in Ouro Preto and Mariana, Brazil. Some participants were enrolled in support institutions such as the Child and Adolescent Psychosocial Care Center (CAPSij) and the Association of Parents and Friends of the Exceptional (APAE) in Ouro Preto. The sample size corresponded to all eligible participants with ASD enrolled in specialized support institutions who consented to participate in the study, ensuring full inclusion of the accessible and willing population.

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Given the limited number of eligible individuals, a randomized design was not feasible, and the sensory evaluation protocol was adapted to the participants' specific communication and behavioral characteristics. To minimize stress and ensure reliable responses, assessments relied on both direct tasting by the children/adolescents and the observations of their caregivers, a common approach in sensory research with populations presenting communication challenges.

In the first stage, a sociodemographic questionnaire was administered to characterize the sample. The second stage assessed caregivers' perceptions of the cookies' familiarity and potential acceptance at home. In the third stage, the sensory acceptance of the cookies was evaluated by the children and adolescents with ASD, with caregiver assistance. Each participant received two units of each formulation (control, 30%, 50%, and 70% substitution), packaged in sealed plastic bags containing approximately 30 g per sample (totaling 240 g). Samples were coded with random three-digit numbers to ensure blind testing.

Affective responses were collected using a 5-point hedonic scale (1 = extremely disliked to 5 = extremely liked) for aroma, flavor, and texture,[32] based on caregivers' observations of the children's reactions. Caregivers who also tasted the samples completed the same evaluation directly.

Statistical analysis

Descriptive analysis was applied to nutritional composition data based on TBCA.[28] For instrumental color parameters, iron content, iron bioaccessibility, and sensory data, analysis of variance (ANOVA) was performed followed by Tukey's test, with a significance level of 5% ($p < 0.05$). Results are presented as mean ± standard deviation. All statistical procedures were conducted using Sisvar software, version 5.6.[33]

Results and discussion

Nutritional composition of chocolate cookies with partial replacement of wheat flour by black bean flour compared to commercial chocolate cookies

Table 2 presents the nutritional composition of chocolate cookies formulated with partial substitution of wheat flour by black bean flour, alongside a commercial chocolate-flavored cookie.

Table 2 Nutritional information for chocolate cookies made by partially replacing wheat flour with black bean flour and commercial chocolate-flavored cookies

Nutrients	Formulations (%)				Commercial
	0	30	50	70	
Caloric Value(Kcal)	164.2	165	163.4	163	196
Carbohydrates(g)	24.68	23.94	23.45	23	24
Proteins (g)	2.71	3.24	3.59	3.94	2.2
Total Fats(g)	6.14	6.14	6.14	6.13	10
Saturated Fat(g)	3.42	3.41	3.41	3.41	5.2
Trans Fat(g)	0.15	0.15	0.14	0.14	0
Fibers(g)	0.5	1.4	1.9	2.5	1.4
Sodium(mg)	28	28	28	28	54

Data for a 40 gram serving (two cookies)

The commercial cookie displayed a significantly higher caloric content compared to all experimental formulations developed in this study. Formulations incorporating black bean flour, especially those with a 70% substitution, showed a reduced carbohydrate content relative to the commercial counterpart. As highlighted by Oliveira et al,[34] a balanced diet should align caloric intake with individual energy needs while ensuring the adequate provision of essential nutrients for health maintenance. Although carbohydrates are a key component of a balanced diet, excessive consumption of refined carbohydrates has been associated with metabolic disorders, including obesity and type 2 diabetes mellitus.[35]

Moreover, the formulation containing 70% black bean flour exhibited a higher protein content compared to the commercial cookie. Proteins play a fundamental role not only in tissue synthesis and repair but also in the regulation of physiological processes, acting as structural components of hormones, enzymes, and antibodies, elements essential to numerous biological and metabolic functions.[36,37]

The commercial cookie exhibited significantly higher levels of total and saturated fats compared to the experimental formulations (Table 2). The trans-fat content in the experimental cookies was minimal, deriving solely from the butter used, and remained below the 0.5 g threshold considered negligible according to Normative Instruction No. 75,[38] thus meeting public health standards. In contrast, the commercial cookie was prepared exclusively with vegetable fats, which accounts for the absence of trans fats in its nutritional labeling.

Formulations with 50% and 70% wheat flour substitution exhibited higher dietary fiber content compared to the commercial cookie, indicating a more favorable nutritional profile. Dietary fiber plays a key role in digestive health and appetite regulation.[39] Additionally, increased fiber intake has been associated with reductions in serum lipid levels, improved blood pressure regulation, prevention of intestinal disorders,[40,41] and enhanced glycemic control, an important factor in the prevention and management of type 2 diabetes.[42]

Finally, the commercial cookie contained nearly twice the amount of sodium compared to the experimental formulations. Excessive sodium intake has been linked to adverse health outcomes, including hypertension, cardiovascular disease, renal impairment, fluid retention, and increased risk of osteoporosis.[43,44]

Physicochemical properties of chocolate cookies with partial wheat flour replacement by black bean flour

Table 3 presents the mean physicochemical parameters of the experimental cookie formulations. All cookies containing black bean flour exhibited reduced lightness (L*) compared to the control formulation (0% substitution), likely due to natural pigments such as anthocyanins, which impart a darker coloration.[45] Additionally, Maillard reactions between black bean proteins and sugars during baking intensified browning.[46,47] The pre-roasting of black bean flour further enhanced browning, contributing to the reduced luminosity.[48]

Chroma (C*) values were below 60 across all formulations, indicating relatively neutral and subdued coloration.[49] Hue angle (°hue) analysis revealed significant differences ($p \leq 0.05$) among the formulations. Cookies with 30% black bean flour substitution showed higher °hue values, indicative of a redder tone, likely due to intermediate Maillard reaction products.[50,51] In contrast, the 0% and 50% substitution formulations exhibited lower °hue values, reflecting darker hues caused by anthocyanins and proanthocyanidins, which absorb specific wavelengths of light.[52]

Iron content ranged from 3.29 mg/100 g in the control formulation (0% substitution) to 4.05 mg/100 g in the 30% substitution formulation (Table 3). Considering age-specific dietary iron recommendations,7 mg/day for children aged 1–3 years, 15 mg/day for adolescents aged 14–18 years, 8 mg/day for adult men, and 18 mg/day for women of reproductive age, decreasing after menopause, these levels represent a meaningful contribution to dietary iron intake, particularly for children and adolescents with varying developmental needs.[53]

More critical than total iron content, however, is its bioaccessibility, defined as the fraction of iron available for absorption, which is influenced by dietary components.[54] Among the formulations, the 30% substitution sample exhibited the highest *in vitro* iron bioaccessibility (15.71%) compared to the 50% and 70% substitution formulations (Table 3), suggesting an optimal balance between iron content and bioavailability ($p \leq 0.05$).

Table 3 Average results of the physical-chemical parameters of chocolate cookies made with partial replacement of wheat flour by black bean flour

Physicochemical parameters	Formulations (%)			
	0	30	50	70
L*	29.23 ± 0.50a	23.17 ± 2.15b	25.53 ± 0.45b	22.90 ± 1.20b
C*	15.40 ± 0.20a	16.10 ± 0.30a	12.90 ± 0.60b	15.20 ± 0.1a
°Hue	59.17 ± 1.55c	72.57 ± 1.35a	57.17 ± 0.45c	68.07 ± 0.75b
Iron (mg/100 g)	3.29 ± 0.08b	4.05 ± 0.28a	3.79 ± 0.16ab	3.78 ± 0.18ab
In vitro bio accessibility (%)	12.66 ± 2.37a	15.71 ± 0.45a	6.49 ± 0.17b	7.59 ± 0.00b

Mean values with common letters in the same lines indicate that there is no significant difference among samples ($p \leq 0.05$) from Tukey's mean test.

The lower bioaccessibility observed at higher substitution levels is likely attributable to the increased presence of antinutritional factors, such as phytates and tannins, commonly found in legumes, which can chelate iron and hinder its solubilization and intestinal absorption.[31] Furthermore, even formulations with lower levels of black bean flour exhibited iron bioaccessibility below 16%, reflecting the predominance of poorly absorbed non-heme iron and the absence of enhancers of iron absorption, such as vitamin C.[54,19]

It is important to note that in vitro digestion models, although widely used for screening and comparative purposes, provide only an approximation of iron bioaccessibility and cannot fully account for the complexity of *in vivo* absorption.[55] Factors such as gastrointestinal physiology, individual nutritional status, the presence of other dietary components consumed in the same meal, and interactions with the gut microbiota can significantly influence actual iron uptake.[56] Therefore, the values reported here should be interpreted with caution, and further *in vivo* studies are necessary to confirm the nutritional impact of these formulations on iron status.

Food selectivity in children and adolescents with Autism Spectrum Disorder (ASD) participating in the study

Demographic characteristics

Table 4 presents the gender and age distribution of children and adolescents with ASD included in the study. A marked male predominance was observed (73.33%) compared to females (26.67%), aligning with epidemiological data reporting ASD prevalence approximately four times higher in males.[57–59] Age distribution was relatively balanced, with most participants (66.67%) between 3 and 8 years old and the remainder (33.33%) between 9 and 14 years old, providing a representative sample across key developmental stages.

Table 4 Distribution of gender and age characteristics of children and adolescents with ASD assisted by the research

Characteristics	Children and adolescents	
	n	Frequency (%)
Gender		
Female	4	26.67
Male	11	73.33
Age range		
3 to 5 years	5	33.33
6 to 8 years	5	33.33
9 to11 years	4	26.67
12 to 14 years	1	6.67

Food selectivity assessment

Figure 1 illustrates a word cloud generated from responses to the question "Which foods does your child refuse due to texture?" The most frequently rejected items included beans, rice, mixed pasty foods, broths, stews, vegetables, and bananas. These findings align with previous studies indicating that children with ASD commonly avoid fruits, vegetables, legumes, meats, and certain soft-textured cereals, often due to oral sensory hyper responsiveness and aversions to complex textures.[60–62] Typically, these children exhibit a preference for crunchy, uniform, and semi-dry textures.[63]

Figures 2a and 2b present word clouds derived from the questions "What foods has your child consumed in the last 3 days?" and "Are there foods your child frequently consumes (4–5 times daily)?" Biscuits emerged as the most frequently consumed food, primarily industrialized products. Dietary trend studies have reported increased consumption of meat and ultra-processed foods, such as soft drinks, biscuits, and ready-to-eat meals, accompanied by a decline in the intake of legumes, roots, tubers, fruits, and vegetables in Brazil over recent decades.[64–67] This pattern appears to be intensified in individuals with ASD, who tend to prefer energy-dense, nutrient-poor, highly processed foods.[68–71,63]

Figure 1 Word cloud illustrating foods commonly refused by children and adolescents with ASD participating in the study.

Figure 2a

Figure 2b

Figure 2 Word clouds of reported food consumption by children and adolescents with ASD: (a) all foods consumed over a three-day period; (b) foods consumed with high frequency (4–5 times per day).

Sensory evaluation of chocolate cookies with black bean flour

Table 5 summarizes parental/guardian perceptions prior to the consumption of black bean flour cookies. Most respondents (73.33%) perceived the cookies as similar to foods typically consumed by their children, while 26.67% disagreed. Acceptance levels were high, with 80% of caregivers expressing willingness to offer the product to their child, a noteworthy outcome given the pronounced food selectivity often observed in children with ASD.[68,72,73]

Table 5 Perception of parents or guardians regarding chocolate cookies with black bean flour before consumption

Characteristics	Parents or guardians	
	n	Frequency (%)
Is it similar to the cookie you often consume?		
Yes	11	73.33
No	4	26.67
Would you be willing to eat chocolate cookies with black bean flour?		
Yes	12	80
No	3	20

Figure 3 displays a word cloud generated from responses to the question "Do you think your child will accept this food at home? Why?" Many parents anticipated acceptance due to the cookie format and its visual and textural similarity to industrialized products, consistent with previously reported preferences for processed foods in this population.[74]

Figure 3 Word cloud of reasons reported by parents or guardians for their children's acceptance of chocolate cookies.

Table 6 presents sensory perceptions during and after consumption. A decrease in aroma detection was observed with increasing levels of black bean flour, suggesting a potential negative effect on aroma perception. Aroma approval was highest in the 0% substitution cookies (100% acceptance), although the 0%, 50%, and 70% formulations all received generally favorable ratings.

Table 6 Perception of parents or guardians regarding chocolate cookies with black bean flour during and after consumption

	Formulations (%)			
Frequency (%)	**0**	**30**	**50**	**70**
Did you smell the cookie?				
Yes	46.16	46.15	38.46	30.77
No	38.46	53.85	61.54	61.54
Did not respond	15.38	0	0	7.69
Did you like the aroma of the cookie?				
Yes	100	33.34	80	75
No	0	33.33	0	25
Did not respond	0	33.33	20	25
Did you like the cookie?				
Yes	61.54	53.85	61.54	53.84
No	15.38	46.15	38.46	23.08
Did not respond	23.08	0	0	23.08
Did you consume the entire sample?				
Yes	46.16	38.46	46.15	46.16
No	38.46	61.64	53.85	38.46
Did not respond	15.38	0	0	15.38
Did parents try it?				
Yes	61.54	69.23	76.92	53.85
No	23.08	30.7	23.08	38.46
Did not respond	15.38	0	0	7.69

Child acceptance was greatest for the 0% and 50% substitution cookies. Complete consumption of the samples was most frequent in the 0% and 70% substitution groups. Notably, many parents also tasted and consumed the cookies, regardless of the black bean flour concentration.

Tables 7, Table 8 displays the mean acceptability scores from parents/guardians and children/adolescents, respectively. No significant differences ($p > 0.05$) were observed across formulations for aroma, flavor, or texture. Scores ranged from "neither liked nor disliked" to "liked very much," indicating that the incorporation of black bean flour did not negatively impact sensory quality.

Table 7 Average results of the acceptability of the different chocolate cookie formulations carried out by parents or guardians

Attributes	**Formulations (%)**			
	0	**30**	**50**	**70**
Aroma	4.13 ± 0.83a	4.33 ± 1.00a	4.40 ± 0.84a	4.00 ± 1.00a
Flavor	4.25 ± 1.06a	4.33 ± 1.05a	4.50 ± 1.23a	3.71 ± 1.25a
Texture	3.62 ± 0.89a	4.11 ± 0.87a	4.20 ± 1.27a	3.71 ± 1.25a

Mean values with common letters in the same lines indicate that there is no significant difference among samples ($p \leq 0.05$) from Tukey's mean test.

Table 8 Average results of the acceptability of different chocolate cookie formulations by children and adolescents assisted by the research

Attributes	**Formulations (%)**			
	0	**30**	**50**	**70**
Aroma	3.85 ± 0.90a	3.54 ± 1.05a	3.54 ± 1.33a	3.92 ± 1.38a
Flavor	3.92 ± 1.19a	3.46 ± 1.20a	3.62 ± 1.56a	3.77 ± 1.30a
Texture	3.85 ± 1.14a	3.38 ± 1.50a	3.46 ± 1.45a	3.85 ± 1.34a

Mean values with common letters in the same lines indicate that there is no significant difference among samples ($p \leq 0.05$) from Tukey's mean test.

These results support prior studies showing that alternative flours can enhance nutritional profiles without compromising sensory acceptance.[75,76] Although food selectivity is a common barrier to the acceptance of new foods in individuals with ASD,[77] the inclusion of black bean flour up to 70% did not significantly diminish cookie acceptability.

Practical considerations for scaling up

Following the positive sensory acceptance results, it is important to consider practical aspects related to the potential scale-up of production for the black bean flour-substituted cookies. Cost implications include the price and availability of black bean flour compared to wheat flour, which may vary regionally and influence the overall affordability of the product.

Moreover, ingredient sourcing must take into account seasonal variations and supply chain reliability to ensure consistent quality and steady supply. Additionally, black beans are recognized allergens for some individuals, necessitating proper allergen labeling and risk assessment prior to large-scale commercialization.

Cultural acceptance also represents a critical factor for successful implementation. While sensory evaluation indicated good acceptance among children with ASD in this study, broader testing is needed across different demographic groups to evaluate market acceptance and consumer preferences. Addressing these considerations will be essential to achieving successful commercialization and widespread adoption of these functional cookies.

Conclusion

This study demonstrates that the incorporation of alternative ingredients, such as black bean flour, constitutes a viable and innovative approach for the development of nutritionally enhanced food products that align with contemporary dietary guidelines and health promotion strategies, particularly targeting populations with specific nutritional requirements. Partial substitution of wheat flour with black bean flour in cookies effectively improved their nutritional profile while preserving acceptable sensory characteristics.

The formulation containing 30% black bean flour exhibited the optimal balance between total iron content and in vitro bioaccessibility, whereas the 70% substitution yielded the highest protein content, increased dietary fiber, reduced caloric value, and lower saturated fat levels compared to commercial controls. Although the *in vitro* iron bioaccessibility results provide valuable preliminary insights, they should be interpreted cautiously as they do not fully replicate in vivo absorption dynamics. Further in vivo studies are necessary to confirm the nutritional benefits of the developed formulations.

Physicochemical and sensory evaluations confirmed that black bean flour inclusion did not detrimentally affect texture, color, or overall acceptability. Notably, the positive acceptance observed among children with Autism Spectrum Disorder (ASD) indicates that, with suitable sensory adaptation, nutritionally superior foods can be successfully integrated into their diets, thereby supporting a more inclusive and health-promoting nutritional strategy. The elevated protein content is especially pertinent given the unique nutritional demands frequently associated with this population.

Based on these results, a 70% black bean flour formulation is recommended for individuals with ASD due to its enhanced protein and fiber content alongside reduced levels of unfavorable fats, while a 30% substitution may be preferable when optimizing iron bioaccessibility is a priority.

The present study has some limitations that should be acknowledged. The small sample size, comprising all eligible and willing participants with ASD from the target institutions, limits statistical power and the generalizability of the results. The non-randomized design was necessitated by logistical constraints and ethical considerations inherent in working with a specialized population. Additionally, the sensory evaluation relied partly on caregiver-assisted observations, an indirect method adapted to the participants' communication and behavioral characteristics. Future research should aim to involve larger and more diverse cohorts, adopt randomized designs where feasible, and explore complementary sensory assessment methods, including standardized and more objective measurement tools, as well as training for caregivers to improve the reliability of observations. Clarification of blinding procedures, control of potential order effects, and detailed reporting to enhance replicability are also recommended in future iterations.

Beyond their nutritional and sensory merits, the development of such functional foods aligns with broader public health objectives and the advancement of sustainable food systems. This work contributes to mitigating nutritional inequities and fostering food security among vulnerable populations, in accordance with the Sustainable Development Goals (SDGs) 2 (Zero Hunger), 3 (Good Health and Well-being), and 12 (Responsible Consumption and Production).

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None

Conflicts of interest

The authors declare no conflicts of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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