Attractive : Innovative Education Journal
Vol. 8 No. 3, November 2026

Toward an Educational Understanding of Gut–Brain Pathways: Dietary Influences, Behavioral Regulation, and Classroom Engagement in ASD

Mennatallah El-Sabagh[1]*, Juhanaini[1], Endang Rochyadi[1], Yoga Budhi Santoso[1], Budi Susetyo[1], Iding Tarsidi[1], Ajeng Suryani[1]
[1] *Universitas Pendidikan Indonesia Bandung, Indonesia*

menna.elsabagh@upi.edu*

ARTICLE INFO
Article history:
Received
May 17, 2026
Revised
August 31, 2026
Accepted
September 16, 2026

ABSTRACT

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by persistent difficulties in social communication and behavioral–attentional regulation, which in inclusive education settings manifest as reduced sustained attention, emotional regulation, and classroom participation. This integrative literature review synthesizes contemporary theoretical and empirical evidence on the relationship between dietary-related physiological mechanisms and classroom-relevant behavioral outcomes. A structured search of Scopus, PubMed, ScienceDirect, and Google Scholar was conducted to identify relevant peer-reviewed literature. Retrieved studies were screened by inclusion and exclusion criteria and synthesized thematically. Findings suggest that microbiota-targeted and multicomponent dietary interventions may be associated with improvements in behavioral regulation, although results remain heterogeneous across studies and intervention types. Reported effects include reductions in irritability, improved emotional stability, and decreased sensory dysregulation, which may support behavioral readiness for structured learning. The review concludes that dietary interventions should be understood as indirect facilitators of educational accessibility rather than direct cognitive enhancers. These findings support the integration of nutritional considerations within inclusive education frameworks through multidisciplinary collaboration among educators, families, and healthcare professionals to enhance classroom engagement in students with ASD.

Keywords: Autism Spectrum Disorder; Behavioral Regulation; Classroom Engagement; Dietary Interventions; Gut–Brain Axis.

Journal Homepage https://attractivejournal.com/index.php/aj/

Published by CV. Creative Tugu Pena

INTRODUCTION

Autism Spectrum Disorder (ASD) is a heterogeneous neurodevelopmental condition characterized by persistent deficits in social communication, restricted and repetitive behaviors, and atypical sensory processing (American Psychiatric Association, 2022; Lord et al., 2018).An estimated more than 1% of the global population is believed to be autistic, representing approximately 78 million individuals worldwide and reflecting the substantial epidemiological and societal burden associated with ASD (Woods et al., 2024; Wu & Su, 2024).Clinical and research attention has traditionally focused on interventions targeting core domains of impairment, including social functioning, sensory processing, and communication difficulties (Woods et al., 2024). These core characteristics often manifest in educational settings as difficulties in sustaining attention, regulating emotions, and responding to instructional

demands, which may reduce participation in structured learning activities and limit classroom engagement in inclusive education contexts.

Behavioral regulation and attentional control are key determinants of academic engagement in ASD. Children with ASD commonly experience behavioral and attentional challenges that may interfere with learning participation and classroom interaction. In addition, challenges in executive functioning, including inhibitory control, working memory, and cognitive flexibility, further affect the ability to sustain goal-directed learning behaviors in classroom environments (Ko et al., 2024). Atypical sensory processing may contribute to emotional dysregulation and behavioral instability in individuals with ASD (Patil & Kaple, 2023), potentially affecting participation in structured learning environments and educational accessibility. From an inclusive education perspective, these challenges highlight the need to explore factors that may support behavioral readiness for learning. Recently, increasing attention has been directed toward non-pharmacological and complementary approaches that may indirectly enhance classroom engagement by improving behavioral regulation. Among these, dietary interventions such as gluten-free/casein-free (GFCF) diets, omega-3 fatty acid supplementation, and probiotic-based strategies have been investigated for their potential role in supporting behavioral and attentional outcomes in children with ASD (Jiang et al., 2023; Abbasi et al., 2024; Doaei et al., 2021).

These interventions are linked to the gut–brain axis, a bidirectional communication system connecting the gastrointestinal tract and the central nervous system (Młynarska et al., 2025; Almohmadi, 2024). Although primarily examined in biomedical contexts, emerging evidence suggests that gastrointestinal dysregulation, including microbiota imbalance and increased intestinal permeability, may contribute to systemic inflammatory processes that are associated with behavioral dysregulation (Di Vincenzo et al., 2024). The gut–brain axis has been proposed as a conceptual framework through which these physiological processes may interact with behavioral functioning in ASD (Zhang et al., 2025). Within this scope, recent randomized controlled trials have reported potential associations between targeted nutritional supplementation and physiological markers relevant to behavioral regulation; for instance, Mazahery et al. (2019) found that combined nutritional strategies involving polyunsaturated fatty acids were associated with improvements in selected neurobehavioral outcomes in children, although variability in response was observed. Such physiological processes may indirectly relate to behavioral functioning, including emotional regulation and attentional processes relevant to classroom engagement. However, the existing literature remains fragmented across biomedical, nutritional, and educational domains. While some studies report improvements in behavioral outcomes following dietary interventions (Amadi et al., 2022), others demonstrate limited or inconsistent effects, particularly in isolated supplementation approaches (Mankad et al., 2015). More importantly, most studies focus on clinical or physiological outcomes, with limited translation into classroom-based educational implications. Despite growing interest in dietary interventions for ASD, limited attention has been given to how physiological and behavioral changes may translate into classroom engagement and learning participation in inclusive education settings. There is a lack of educationally oriented syntheses that connect dietary-related physiological processes with behavioral regulation and classroom engagement outcomes in students with ASD. Accordingly, this integrative review aims to synthesize contemporary theoretical and empirical evidence on dietary interventions in ASD through an educational lens, focusing on their indirect role in supporting learning-relevant behavioral and attentional processes associated with classroom engagement. This review proposes an educational interpretation of existing biomedical evidence on the gut–brain axis through a learning-centered lens. Within this framework, dietary interventions are conceptualized as indirect modulators of behavioral readiness rather than direct determinants of cognitive outcomes.

METHOD

This study employed an integrative literature review design to collect, evaluate, and synthesize existing biomedical and educational literature. The review aimed to explore the

relationships between dietary-related physiological mechanisms, behavioral regulation, and classroom engagement in Autism Spectrum Disorder (ASD), with the goal of generating a conceptual synthesis across interdisciplinary domains.

Data Sources and Search Strategy

Literature was identified from major academic databases, including Scopus, PubMed, and ScienceDirect, with supplementary searches conducted through Google Scholar to ensure broader coverage of relevant literature. A structured search approach was used with combinations of keywords related to Autism Spectrum Disorder (ASD), dietary interventions (e.g., gluten-free/casein-free diets, omega-3 supplementation, probiotics), and behavioral and educational outcomes such as attention, behavioral regulation, and classroom engagement. The literature search was conducted between April and June 2026 and included studies published up to 2026. Duplicate records were removed prior to analysis.

Study Selection

Relevant studies were selected based on their alignment with the review objectives. The selection process involved identification of literature from the selected databases, screening for relevance to the review focus, and inclusion of studies that met the predefined criteria. The review focused on literature examining dietary interventions in ASD and reporting outcomes related to behavioral regulation, attention, emotional stability, or educational engagement. As an integrative literature review, this study aimed to conceptually integrate relevant findings across biomedical, nutritional, and educational domains rather than provide an exhaustive systematic synthesis of all available evidence.

Inclusion and Exclusion Criteria

Included studies involved children or adolescents diagnosed with ASD and examined dietary interventions such as gluten-free/casein-free diets, omega-3 fatty acids, or probiotic supplementation. Eligible studies reported behavioral or educationally relevant outcomes, including attention, emotional regulation, behavioral stability, or classroom participation. Only peer-reviewed journal articles were considered.

Studies were excluded if they focused solely on pharmacological treatments, lacked behavioral or educational outcomes, were non-peer-reviewed, or were based exclusively on animal studies without direct relevance to human educational contexts.

Quality Considerations

The methodological quality of the included literature was considered during synthesis. Greater emphasis was placed on findings from systematic reviews, randomized controlled trials, and well-designed observational studies when available. However, all included evidence was interpreted within the context of its methodological limitations and heterogeneity.

Time Frame

The review included literature published between 2015 and 2026, with particular attention to recent studies from 2022 to 2026. Foundational theoretical works on ASD, sensory processing, and executive functioning were also included to support conceptual framing.

Data Analysis and Synthesis

A thematic synthesis approach was used to identify recurring patterns across the literature. Findings were organized into three conceptual domains: (1) neurobiological mechanisms, (2) behavioral regulation in relation to classroom engagement, and (3) implications for inclusive educational practice.

Interpretive Lens

The analysis was guided by a behavioral–educational interpretive lens. Dietary interventions were conceptualized as indirect contributors to physiological stability and behavioral readiness rather than direct cognitive enhancers. Behavioral changes such as irritability, sensory dysregulation, and emotional instability were interpreted in relation to classroom engagement indicators including attention, task persistence, and participation.

Ethical Considerations

This study relied exclusively on publicly available peer-reviewed literature and did not involve human or animal participants. Ethical standards were maintained through accurate citation practices and balanced representation of findings.

RESULTS AND DISCUSSION

Based on the comprehensive search and selection process, a total of 50 peer-reviewed articles were included in the final synthesis. To facilitate interpretation of the reviewed evidence, the findings are organized into several interconnected thematic domains. These domains examine dietary interventions, gut–brain communication pathways, behavioral regulation, and their educational relevance to classroom engagement among students with Autism Spectrum Disorder (ASD).

Behavioral Regulation as a Functional Access Domain

Behavioral regulation represents a core functional domain that determines students' ability with ASD to access classroom learning environments. It encompasses sustained attention, emotional stability, and the capacity to respond to instructional demands. In inclusive settings, impairments in this domain commonly manifest as irritability, emotional dysregulation, and aggressive behaviors (Baweja et al., 2023), alongside executive functioning difficulties (Christoforou et al., 2023).

Executive functioning difficulties may further constrain goal-directed behavior and adaptive responding within structured learning contexts (Ko et al., 2024). These cognitive-behavioral constraints have been proposed to be influenced by dietary and lipid-related mechanisms. In this context, Keim et al. (2022) reported in a randomized controlled trial that tailored fatty acid interventions were associated with improvements in executive functioning measures in children with neurodevelopmental conditions, although variability in response was observed. Additionally, atypical sensory processing increases vulnerability to environmental stimuli, potentially affecting emotional regulation and behavioral consistency during instruction (Patil & Kaple, 2023). Importantly, behavioral regulation is conceptualized here as a functional access condition to education rather than a proxy for cognitive capacity.

Dietary Interventions as Biopsychological Modulators

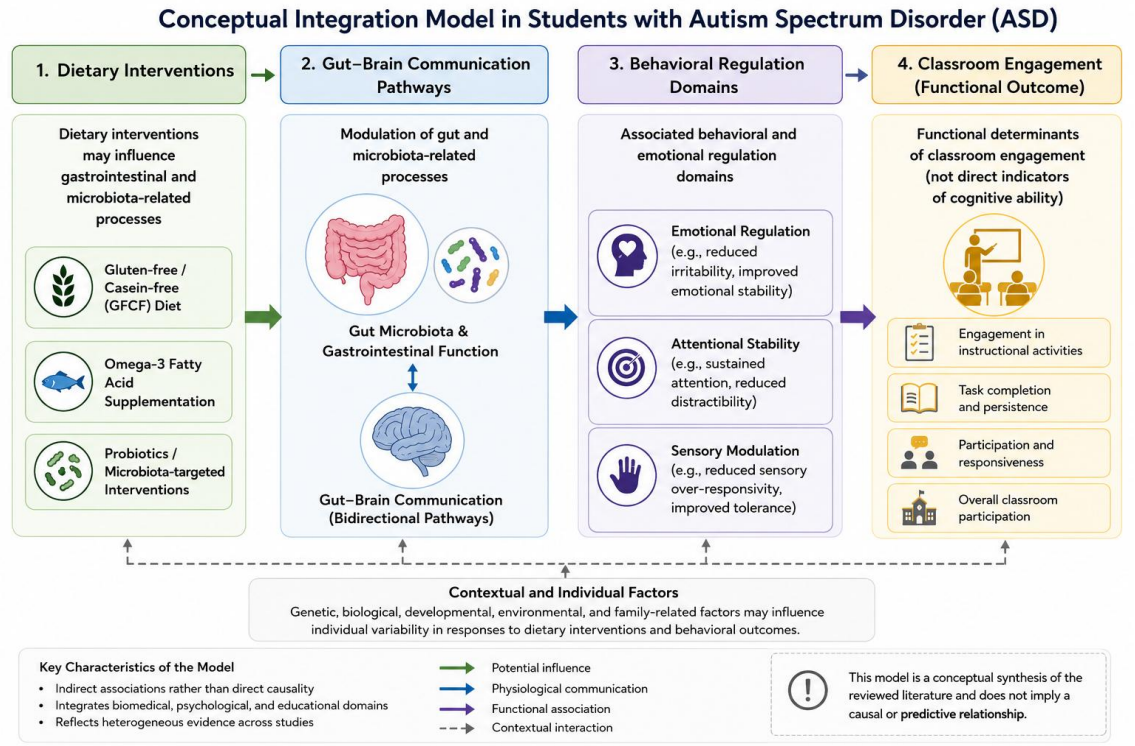
Dietary interventions, including gluten-free/casein-free (GFCF) diets, omega-3 fatty acid supplementation, and probiotics, have been investigated as potential modulators of physiological and behavioral functioning in individuals with ASD. Evidence suggests that dietary modification may be associated with changes in irritability, attention, and emotional regulation; however, findings remain inconsistent across studies (Abbasi et al., 2024; Doaei et al., 2021). Similar variability has been reported in studies on GFCF diets (Saad et al., 2024; Zafirovski et al., 2024), with effect magnitude influenced by sample heterogeneity and methodological differences.

Mechanistically, these interventions are hypothesized to act through gut microbiota modulation and gastrointestinal functioning via gut–brain communication pathways (Feng et al., 2023; Doenyas, 2018), with theoretical support for the microbiota–gut–brain axis in ASD-related outcomes (Zhang et al., 2025).

This evidence remains primarily biomedical in nature and does not directly translate into educational causality.

Gut–Brain Pathway as a Conceptual Integration Framework

To synthesize the relationships identified across the reviewed literature, a conceptual integration model was developed to illustrate the proposed connections among dietary interventions, gut–brain communication pathways, behavioral regulation, and classroom engagement in ASD. The framework is presented in Figure 1.



Source: Developed by the authors based on the reviewed literature.

Figure 1. Conceptual integration model of the relationships among dietary interventions, gut–brain communication pathways, behavioral regulation, and classroom engagement in students with Autism Spectrum Disorder (ASD).

This figure presents a synthesized conceptual framework derived from the reviewed literature, illustrating the proposed indirect associations between dietary interventions (including gluten-free/casein-free diets, omega-3 fatty acid supplementation, and probiotics), gut–brain communication mechanisms, and behavioral regulation processes in individuals with ASD. Within this integrative model, dietary factors are hypothesized to influence gastrointestinal and microbiota-related processes, which are in turn associated with domains of behavioral functioning such as emotional regulation, attentional stability, and sensory modulation. These behavioral domains are positioned as functional determinants of classroom engagement rather than direct indicators of cognitive ability. Importantly, the model does not imply a causal or predictive relationship; instead, it represents a conceptual synthesis of heterogeneous evidence across biomedical, psychological, and educational domains. Accordingly, the framework is intended to support interpretive understanding of potential pathways linking physiological processes to educationally relevant behavioral outcomes in inclusive classroom contexts.

Behavioral Outcomes as Proximal Functional Indicators

Changes associated with dietary interventions are primarily expressed in proximal behavioral domains rather than core cognitive structures. Some studies report modest improvements in attentional regulation, particularly following omega-3 supplementation (Jiang et al., 2023). Evidence regarding gluten-free/casein-free dietary interventions suggests potential improvements in selected behavioral symptoms among some subgroups of individuals with ASD, although findings remain heterogeneous and inconclusive (Saad et al., 2024; Zafirovski et al., 2024). Similarly, probiotic interventions have been associated with improvements in behavioral and gastrointestinal symptoms in some populations (Feng et al., 2023; Santocchi et al., 2020). Recent randomized controlled trial evidence further supports this association. For example, Liu et al. (2023) reported that targeted probiotic supplementation was associated with reductions in behavioral symptom severity and improvements in social responsiveness measures in young populations. Similarly, Guiducci et al. (2024) observed changes in sensory processing profiles and emotional regulation outcomes following microbiome-targeted

interventions. However, these findings remain heterogeneous, and effect consistency across studies is limited.Overall, these effects should be interpreted as variations in behavioral functioning rather than stable cognitive enhancement.

Sensory Processing and Functional School Readiness Conditions

Sensory processing differences in ASD are frequently associated with restrictive eating behaviors and selective food intake patterns (Mathew et al., 2022; Nimbley et al., 2022; Rochedy, 2018). These patterns may contribute to nutritional imbalance and gastrointestinal discomfort, which can influence daily functional stability (Al-Beltagi, 2024; Almohmadi, 2024).

While direct links between dietary patterns and academic achievement remain limited, sensory processing differences and related behavioral regulation challenges may influence participation in learning activities through their effects on attention, emotional regulation, and executive functioning (Ko et al., 2024).

Feeding Behaviors as Contextual School Participation Factors

School participation among students with ASD is also influenced by feeding-related behaviors and environmental meal-time demands. Common challenges include food selectivity, sensory aversion, and disrupted mealtime routines, which may affect daily functioning and social participation in school contexts (Padmanabhan & Shroff, 2022; Galpin et al., 2018).

Emerging evidence suggests that microbiota-targeted interventions, such as probiotics, may yield improvements in gastrointestinal and behavioral outcomes in some cases (Santocchi et al., 2020; Meguid et al., 2022). Additionally, combining biological and behavioral interventions may produce complementary effects on adaptive functioning (Li et al., 2021).

These findings primarily relate to adaptive and behavioral outcomes rather than formal educational performance metrics.

Cognitive Capacity Versus Functional Learning Readiness

A key distinction in the literature is between cognitive capacity and functional readiness for learning environments. Current evidence does not support the conclusion that dietary interventions enhance core cognitive abilities in ASD (Mankad et al., 2015; Amadi et al., 2022; Abbasi et al., 2024). Instead, findings suggest potential modulation of physiological and behavioral states that may indirectly support behavioral readiness for learning (Doaei et al., 2021; Feng et al., 2023). Accordingly, educational interpretation should rely on functional indicators such as engagement, task completion, and instructional responsiveness rather than cognitive test scores alone (Leifler, 2023).

Educational Implications for Inclusive Practice

From an inclusive education perspective, dietary interventions should be understood as adjunctive supports that may contribute to behavioral stability under specific conditions rather than independent educational interventions.

However, translation of biomedical evidence into classroom practice remains limited due to heterogeneity in findings and insufficient school-based research (Amadi et al., 2022; Soleimanpour et al., 2024). Within a multidisciplinary framework, dietary considerations may complement structured educational strategies such as individualized education plans (IEPs), structured teaching, and behavioral interventions (Leifler, 2023). Parental knowledge may further influence the consistency of dietary intervention implementation across home and school contexts (Hasanah et al., 2022).

Table 1. Summary of Dietary Interventions, Reported Behavioral Outcomes, and Educational Interpretations in ASD

The reviewed evidence highlights three main intervention categories with distinct but non-convergent behavioral and physiological profiles. To provide an integrated overview of the reviewed evidence, Table 1 summarizes the major dietary interventions discussed in the literature:

Intervention	Behavioral/Physiological Effects	Educational Implications	Limitations
Gluten-Free / Casein-Free (GFCF) Diet	May reduce irritability and gastrointestinal symptoms in some subgroups (Saad et al., 2024; Zafirovski et al., 2024).	Potential improvements in irritability and gastrointestinal discomfort may indirectly support behavioral regulation relevant to classroom engagement.	Findings are heterogeneous and largely dependent on caregiver-reported outcomes and variability in study design.
Omega-3 Fatty Acid Supplementation	Proposed anti-inflammatory and neurophysiological effects, with mixed behavioral outcomes (Jiang et al., 2023; Abbasi et al., 2024).	May be associated with modest improvements in attentional regulation and behavioral stability in some cases.	Evidence remains inconsistent, with variability in sample size, dosage, and methodological quality across studies.
Probiotics / Microbiota-targeted Interventions	Modulation of gut microbiota with potential effects on gastrointestinal functioning and behavioral symptoms (Feng et al., 2023).	May contribute to improvements in gastrointestinal comfort and limited behavioral regulation outcomes (e.g., irritability, emotional stability) in some individuals.	Preliminary evidence with high heterogeneity across strains, intervention protocols, and outcome measures.

Note: The educationally relevant implications presented in this table are interpretive extensions derived from behavioral and physiological findings reported in the reviewed literature. They do not represent directly measured educational outcomes and should therefore be understood as conceptual inferences rather than empirically validated classroom effects. Overall, effects remain preliminary and context-dependent rather than generalizable educational outcomes.

Classroom Implications for Inclusive Education Practice

Effective support for students with ASD requires recognition of behavioral regulation as a key functional determinant of classroom participation.

Instructional practice should prioritize structured environments, predictable routines, and individualized supports (Leifler, 2023). Consistent daily routines may further support behavioral stability and participation (Hatherly et al., 2022).

Based on inclusive education literature, practical classroom strategies may include:

- reducing sensory overload and behavioral triggers
- supporting attention and task persistence
- aligning instruction with IEPs
- implementing sensory-friendly classroom adjustments
- ensuring cross-environment consistency through family collaboration

Dietary interventions should be interpreted as supportive contextual factors that complement, rather than replace, evidence-based educational and behavioral interventions such as Applied Behavior Analysis (ABA).

Limitations

This review is limited by heterogeneity across included studies in design, sample characteristics, interventions, and outcome measures. Most evidence derives from biomedical and behavioral research rather than direct classroom-based investigations.

Therefore, educational interpretations presented in this synthesis should be considered conceptual extrapolations rather than empirically validated classroom effects.

DISCUSSION

This review provides a novel educational interpretation of the growing literature on dietary interventions and gut–brain axis mechanisms in Autism Spectrum Disorder (ASD). While previous research has predominantly examined these interventions from biomedical and clinical perspectives, the present study extends the discussion by conceptualizing dietary influences as potential contributors to behavioral readiness for learning. The primary novelty of this review lies in its integration of nutritional, neurobiological, and educational evidence into a unified framework that links physiological regulation with classroom engagement. Rather than framing dietary interventions as direct treatments for cognitive deficits, this review proposes that their educational relevance may emerge through indirect effects on behavioral regulation, emotional stability, and attentional functioning, all of which are essential prerequisites for participation in inclusive learning environments.

The findings indicate that dietary interventions, particularly microbiota-targeted approaches, omega-3 supplementation, and gluten-free/casein-free dietary modifications, may be associated with improvements in selected behavioral domains among some individuals with ASD. Across the reviewed studies, the most commonly reported outcomes included reductions in irritability, improved emotional regulation, enhanced gastrointestinal functioning, and modest improvements in attentional stability. However, these effects were neither universal nor consistent across all studies. Importantly, the reviewed evidence does not support the conclusion that dietary interventions directly improve cognitive ability or academic achievement. Instead, the findings suggest that physiological and behavioral stabilization may create conditions that indirectly facilitate classroom engagement, task persistence, and instructional responsiveness.

The findings of the present review are generally consistent with a growing body of literature investigating dietary and microbiota-targeted interventions in ASD. Foundational research on the gut–brain axis has emphasized bidirectional interactions between gastrointestinal physiology, microbial composition, immune signaling, and behavioral functioning, providing a theoretical basis for potential associations between dietary factors and ASD-related outcomes (Cryan et al., 2019; Mayer et al., 2022). Systematic reviews indicate that probiotic and microbiota-targeted interventions may contribute to improvements in gastrointestinal symptoms and selected behavioral outcomes, although the magnitude and consistency of effects vary across studies (Lewandowska-Pietruszka et al., 2023; Wu & Su, 2024).

Recent syntheses have further categorized intervention effects. For instance, Chan et al. (2026) reported that specific microbial strains are associated with improvements in certain social and behavioral domains, although heterogeneity across trials limits firm conclusions. At the neurophysiological level, Billeci et al. (2023) provided randomized controlled trial evidence suggesting that probiotic interventions may be associated with alterations in EEG activity patterns and attentional processes in preschool children, although causal interpretations remain limited. Similarly, Feng et al. (2023) concluded that probiotics may offer potential benefits in behavioral regulation through gut–brain communication pathways, while Santocchi et al. (2020) demonstrated improvements in gastrointestinal, sensory, and selected behavioral symptoms following probiotic supplementation. Additional placebo-controlled evidence has further suggested that microbiome-targeted interventions may improve gastrointestinal functioning and selected behavioral outcomes in children with ASD (Arnold et al., 2019).

Evidence from broader microbiome research further supports an association between gut microbial composition and behavioral manifestations in ASD (Nitschke et al., 2020; Młynarska et al., 2025). In addition to microbiota-targeted approaches, previous studies have reported mixed but potentially beneficial effects of omega-3 supplementation and gluten-free/casein-free (GFCF) dietary interventions. Meta-analytic evidence suggests that omega-3 supplementation may be associated with improvements in selected behavioral domains, although effects on broader developmental outcomes remain limited (Cheng et al., 2017). Likewise, GFCF dietary approaches have been associated with improvements in selected behavioral outcomes in certain studies; however, overall evidence remains heterogeneous and inconclusive (Yu et al., 2022).

Similarly, Mitchell and Davies (2021) reported that prebiotic and probiotic interventions may positively influence gastrointestinal functioning, although evidence for sustained behavioral improvements remains inconclusive. This variability is consistent with findings from more recent clinical trials, where probiotic supplementation has been associated with improvements in gastrointestinal symptoms, quality of life, and selected behavioral outcomes, albeit with heterogeneous effects across participants (Arnold et al., 2019; Santocchi et al., 2020; Liu et al., 2023). Doenyas (2019) similarly argued that individualized dietary approaches targeting gut–immune–brain interactions may hold promise for ASD management but require stronger empirical validation. Furthermore, evidence discussed by Doenyas (2019) indicated that only about 60% of individuals with ASD showed improvement in symptoms, ranging from minor to significant effects, while others reported no benefit or experienced discomfort leading to discontinuation of the dietary regimen, suggesting that such interventions may not be universally effective across all cases. However, unlike most previous studies, which primarily focused on clinical and biomedical outcomes, the present review extends the interpretation of dietary interventions to educational contexts by emphasizing behavioral readiness for learning and classroom engagement as potential downstream outcomes. Taken together, these findings support the current review's conclusion that dietary interventions may influence behavioral functioning and physiological regulation; however, robust evidence linking these interventions directly to educational or cognitive outcomes remains insufficient.

Nevertheless, important inconsistencies remain across the literature. Evidence suggests that multicomponent dietary approaches combining dietary modification with nutritional supplementation may produce more favorable outcomes than isolated interventions targeting a single nutrient. For example, Adams et al. (2018) reported improvements in developmental and behavioral outcomes following a comprehensive nutritional program, whereas Mankad et al. (2015) found limited benefits of omega-3 supplementation, reporting no significant improvements in core ASD symptoms, adaptive functioning, or language outcomes. Similar observations have been Shlighted in recent reviews and meta-analyses, which suggest potential benefits of dietary and microbiota-targeted interventions for selected behavioral and gastrointestinal outcomes in ASD. Nevertheless, although some analyses reported significant improvements in specific subgroups, substantial heterogeneity across studies continues to limit definitive conclusions regarding overall effectiveness. (Amadi et al., 2022; Soleimanpour et al., 2024; Gao et al., 2026).

The similarities observed across studies may be explained by several biological mechanisms associated with different dietary interventions in ASD. In microbiota-targeted approaches, improvements have been linked to modulation of the microbiota–gut–brain axis, including changes in microbial diversity, intestinal permeability, inflammatory activity, immune signaling, and neurochemical pathways (Cryan et al., 2019; Mayer et al., 2022; Młynarska et al., 2025). Similarly, studies examining omega-3 supplementation have suggested that its potential benefits may be related to anti-inflammatory effects and its role in neuronal membrane function and neurodevelopment (Cheng et al., 2017). For gluten-free/casein-free dietary interventions, proposed mechanisms include reductions in gastrointestinal discomfort, improved nutrient absorption, and decreased exposure to dietary components that may exacerbate symptoms in susceptible individuals (Yu et al., 2022; Doenyas, 2019). Such mechanisms may help explain why several studies reported reductions in irritability, emotional dysregulation, and sensory difficulties following dietary or probiotic interventions (Santocchi et al., 2020; Feng et al., 2023). In addition, gastrointestinal comorbidities in individuals with ASD have been associated with a broad range of behavioral and functional difficulties, including sleep disturbances, mood instability, oppositional and disruptive behaviors, anxiety, heightened sensory responsiveness, rigid and compulsive patterns, self-injurious and aggressive behaviors, limited expressive language, and impairments in social functioning (Feng et al., 2023).

A major contribution of this review is the development of an educationally oriented conceptual framework that connects physiological mechanisms to functional participation in classroom settings. Existing literature has largely examined dietary interventions through clinical or biomedical outcomes, whereas the present review emphasizes behavioral regulation as a mediating construct linking gut–brain processes to educational accessibility. By introducing behavioral readiness for learning as a central interpretive concept, this study expands current understanding of how physiological regulation may influence educational participation. This perspective contributes to the growing movement toward interdisciplinary approaches that integrate health-related and educational determinants of student engagement within inclusive education systems.

The findings also have important practical, academic, and policy implications. From an educational perspective, dietary interventions may be considered as complementary supports that could enhance behavioral stability under specific circumstances; however, they should not replace evidence-based educational practices such as individualized education plans (IEPs), structured teaching approaches, and behavioral interventions. This interpretation is consistent with recent meta-analytic evidence suggesting that nonpharmacological behavioral and psychosocial interventions tend to be associated with higher effect sizes for core ASD symptoms (Gu et al., 2026). For researchers, the findings highlight the need for more school-based investigations that directly examine classroom outcomes rather than relying solely on biomedical or clinical indicators. Future studies should employ longitudinal and multidisciplinary designs capable of evaluating whether improvements in gastrointestinal functioning and behavioral regulation translate into measurable gains in classroom engagement, participation, and learning outcomes. From a policy perspective, the findings support greater collaboration among educators, families, nutrition professionals, and healthcare providers to ensure comprehensive support systems for students with ASD across home, clinical, and educational environments.

CONCLUSION

This integrative review suggests that dietary interventions, including gluten-free/casein-free diets, omega-3 supplementation, and probiotics, are associated with improvements in behavioral regulation among children with Autism Spectrum Disorder (ASD). These effects should be interpreted as physiological and behavioral modulation that may indirectly support learning-related functioning, particularly attentional control, emotional stability, and classroom engagement. However, the evidence remains heterogeneous, with variability across study designs, interventions, and individual responses.

Accordingly, dietary strategies should be interpreted as supportive components within multidisciplinary and inclusive education frameworks rather than as standalone interventions or direct determinants of cognitive or academic outcomes. Overall, the findings highlight an indirect pathway between gut–brain-related physiological processes and classroom engagement through behavioral pathways.Future research should prioritize longitudinal, school-based designs that examine the relationships between biological, behavioral, and educational variables in children with Autism Spectrum Disorder (ASD). Studies should aim to use more standardized and well-defined intervention protocols to improve comparability across findings and strengthen the evidence base.

Given the current heterogeneity in outcomes, future investigations should also consider the role of individual differences, including gastrointestinal profiles, sensory processing characteristics, and behavioral variability, in shaping responses to dietary interventions. Dietary strategies, when examined in applied contexts, should be investigated as components of multidisciplinary support approaches rather than isolated interventions. Future school–family collaboration models may benefit from incorporating nutrition education and counseling for caregivers to improve nutritional knowledge and support adherence to dietary interventions (Mulyani et al., 2023). Such approaches may integrate nutritional management with established behavioral and educational approaches to better reflect real-world inclusive education settings.
Future research may explore integrative intervention models that combine biological, behavioral, and educational components, although current evidence remains primarily separated across these domains. Finally, effective implementation of support strategies requires ongoing collaboration among families, educators, healthcare professionals, and nutrition specialists to ensure consistency of support across home and school environments and to enhance the ecological validity of intervention outcomes.

REFERENCES

Abbasi, H., Parhiz, A., Khoshdooz, S., Bakhshimoghaddam, F., Doaei, S., & Gholamalizadeh, M. (2024). Impact of omega-3 fatty acid supplementation on clinical manifestations in autism spectrum disorders: An umbrella review of meta-analyses. *Nutrition Research Reviews*. https://doi.org/10.1017/S0954422424000325

Al-Beltagi, M. (2024). Nutritional management and autism spectrum disorder: A systematic review. *World Journal of Clinical Pediatrics, 13*(4), 99649. https://doi.org/10.5409/wjcp.v13.i4.99649

Almohmadi, N. H. (2024). Brain–gut–brain axis, nutrition, and autism spectrum disorders: A review. *Translational Pediatrics, 13*(9). https://doi.org/10.21037/tp-24-182

Amadi, C. N., Orish, C. N., Frazzoli, C., & Orisakwe, O. E. (2022). Dietary interventions for autism spectrum disorder: An updated systematic review of human studies. *Psychiatriki, 33*(3), 228–242. https://doi.org/10.22365/jpsych.2022.073

American Psychiatric Association. (2022). *Diagnostic and statistical manual of mental disorders* (5th ed., text rev.; DSM-5-TR). https://doi.org/10.1176/appi.books.9780890425787

Arnold, L. E., Luna, R. A., Williams, K., Chan, J., Parker, R. A., Wu, Q., Hollway, J. A., Jeffs, A., Lu, F., Coury, D. L., & Savidge, T. (2019*).* Probiotics for gastrointestinal symptoms and quality of life in autism: A placebo-controlled pilot trial. *Journal of Child and Adolescent Psychopharmacology, 29(9), 659–669*. https://doi.org/10.1089/cap.2018.0156

Baweja, R., Waschbusch, D. A., & Mayes, S. D. (2023). Physical aggression toward others and self: Correlates in autism, ADHD, and population-based samples. *JAACAP Open, 1*(4), 274–283. https://doi.org/10.1016/j.jaacop.2023.07.004

Billeci, L., Callara, A. L., Guiducci, L., Prosperi, M., Morales, M. A., Calderoni, S., Muratori, F., & Santocchi, E. (2023). A randomized controlled trial into the effects of probiotics on electroencephalography in preschoolers with autism. *Autism, 27*(1), 117–132. https://doi.org/10.1177/13623613221082710

Chan, M. X., Hoh, C. Y., Teh, Y. Y., Toh, X. Y., & Ismail, N. A. S. (2026).
Effects of probiotic supplementation on core symptoms of autism spectrum disorder in

children.
Nutrients, 18(7), 1127. https://doi.org/10.3390/nu18071127

Christoforou, M., Jones, E. J. H., White, P., & Charman, T. (2023). Executive function profiles of preschool children with autism spectrum disorder and attention-deficit/hyperactivity disorder: A systematic review. *JCPP Advances, 3*(1), e12123. https://doi.org/10.1002/jcv2.12123

Cryan, J. F., O'Riordan, K. J., Cowan, C. S. M., Sandhu, K. V., Bastiaanssen, T. F. S., Boehme, M., ... & Dinan, T. G. (2019). *The microbiota–gut–brain axis*. *Physiological Reviews, 99*(4), 1877–2013. https://doi.org/10.1152/physrev.00018.2018

Davies, C., Mishra, D., Eshraghi, R. S., Mittal, J., Sinha, R., Bulut, E., Mittal, R., & Eshraghi, A. A. (2021). *Altering the gut microbiome to potentially modulate behavioral manifestations in autism spectrum disorders: A systematic review*. *Neuroscience & Biobehavioral Reviews, 128*, 549–557. https://doi.org/10.1016/j.neubiorev.2021.07.001

Di Vincenzo, F., Del Gaudio, A., Petito, V., Lopetuso, L. R., & Scaldaferri, F. (2024). Gut microbiota, intestinal permeability, and systemic inflammation: A narrative review. *Internal and Emergency Medicine, 19*(2), 275–293. https://doi.org/10.1007/s11739-023-03374-w

Doaei, S., Bourbour, F., Teymoori, Z., Jafari, F., Kalantari, N., Torki, S. A., Ashoori, N., Gorgani, S. N., & Gholamalizadeh, M. (2021). The effect of omega-3 fatty acids supplementation on social and behavioral disorders of children with autism: A randomized clinical trial. *Pediatric Endocrinology, Diabetes and Metabolism, 27*(1), 12–18. https://doi.org/10.5114/pedm.2020.101806

Doenyas, C. (2018). Gut-brain axis dietary interventions in ASD. *Physiology & Behavior, 194*, 577–582. https://doi.org/10.1016/j.physbeh.2018.07.014

Doenyas, C. (2019). *Novel personalized dietary treatment for autism based on the gut-immune-endocrine-brain axis*. *Frontiers in Endocrinology, 10*, 508. https://doi.org/10.3389/fendo.2019.00508

Feng, P., Zhao, S., Zhang, Y., & Li, E. (2023). Probiotics in ASD and gut-brain axis. *Frontiers in Microbiology, 14*, 1123462. https://doi.org/10.3389/fmicb.2023.1123462

Galpin, J., Osman, L., & Paramore, C. (2018). Sensory snack time intervention. *Frontiers in Education, 3*, 77. https://doi.org/10.3389/feduc.2018.00077

Gao, X., Fu, N., Ben, Q., & Bu, X. (2026). *A meta-analysis of the effects of gut microbiota-based interventions on gastrointestinal and behavioral symptoms in children with autism spectrum disorder*. *Nutrition Reviews, 84*(3), 500–513. https://doi.org/10.1093/nutrit/nuaf050

Gu, Y., Fox, M., & Zhao, D. (2026). A systematic review and meta-analysis of pharmacological and nonpharmacological interventions for autism spectrum disorder. *Nature Mental Health*. https://doi.org/10.1038/s44220-026-00652-2

Guiducci, L., Billeci, L., Prosperi, M., Callara, A. L., Calderoni, S., Grossi, E., Muratori, F., & Santocchi, E. (2024). *Sensory profile changes in preschoolers with autism spectrum disorder after probiotic supplementation: Secondary outcomes of a randomized controlled trial*. Research in Autism Spectrum Disorders, 111, 102315. https://doi.org/10.1016/j.rasd.2024.102315

Hasanah, L. N., Fatmawati, D. P., Hidayat, L., & Thalia, R. R. L. A. (2022). Mother's knowledge of gluten and casein free diet on children with autism spectrum disorder (ASD) and its application during COVID-19 pandemic. In *Proceedings of the 1st UPY International Conference on Education and Social Science (UPINCESS 2022)* (pp. 210–216). Atlantis Press. https://doi.org/10.2991/978-2-494069-39-8_19

Hatherly, K., Stienwandt, S., Salisbury, M. R., Roos, L. E., & Fisher, P. A. (2022). Routines as a protective factor for emerging mental health and behavioral problems in children with neurodevelopmental delays. *Advances in Neurodevelopmental Disorders, 7*(1), 35–45. https://doi.org/10.1007/s41252-022-00260-y

Jiang, Y., Dang, W., Nie, H., Kong, X., Jiang, Z., & Guo, J. (2023). Omega-3 polyunsaturated fatty acids and/or vitamin D in autism spectrum disorders: A systematic review. *Frontiers in Psychiatry, 14*, 1238973. https://doi.org/10.3389/fpsyt.2023.1238973

Keim, S. A., Jude, A., Smith, K., Khan, A. Q., Coury, D. L., Rausch, J., Udaipuria, S., Norris, M., Bartram, L. R., Narayanan, A. R., & Rogers, L. K. (2022).
Randomized controlled trial of omega-3 and omega-6 fatty acid supplementation to reduce inflammatory markers in children with autism spectrum disorder.
Journal of Autism and Developmental Disorders, 52(12), 5342–5355. https://doi.org/10.1007/s10803-021-05396-9

Ko, C.-L., Lin, C.-K., & Lin, C.-L. (2024). Relationship between executive function and autism symptoms in preschoolers with autism spectrum disorder. *Research in Developmental Disabilities, 146*, 104692. https://doi.org/10.1016/j.ridd.2024.104692

Leifler, E. (2023). Towards equity and inclusion excellence using diverse interventions. In K. Koreeda, M. Tsuge, S. Ikuta, E. Dalton, & L. Plantin Ewe (Eds.), *Building inclusive education in K–12 classrooms and higher education: Theories and principles* (pp. 59–79). IGI Global. https://doi.org/10.4018/978-1-6684-7370-2.ch004

Lewandowska-Pietruszka, Z., Figlerowicz, M., & Mazur-Melewska, K. (2023). *Microbiota in autism spectrum disorder: A systematic review*. *International Journal of Molecular Sciences, 24*(23), 16660. https://doi.org/10.3390/ijms242316660

Li, Y. Q., Sun, Y. H., Liang, Y. P., Zhou, F., Yang, J., & Jin, S. L. (2021). Effect of probiotics combined with applied behavior analysis in the treatment of children with autism spectrum disorder: A prospective randomized controlled trial. *Zhongguo Dang Dai Er Ke Za Zhi, 23*(11), 1103–1110. https://doi.org/10.7499/j.issn.1008-8830.2108085

Liu, Y. W., Wang, J. E., Sun, F. J., Huang, Y. H., & Chen, H. J. (2023).
Probiotic intervention in young children with autism spectrum disorder: A randomized, double-blind, placebo-controlled trial.
Research in Autism Spectrum Disorders, 109, 102256. https://doi.org/10.1016/j.rasd.2023.102256

Lord, C., Elsabbagh, M., Baird, G., & Veenstra-VanderWeele, J. (2018). Autism spectrum disorder. *The Lancet, 392*(10146), 508–520. https://doi.org/10.1016/S0140-6736(18)31129-2

Mankad, D., Dupuis, A., Smile, S., Roberts, W., Brian, J., Lui, T., Genore, L., Zaghloul, D., Iaboni, A., Marcon, P. M. A., & Anagnostou, E. (2015). A randomized, placebo-controlled trial of omega-3 fatty acids in the treatment of young children with autism. *Molecular Autism, 6*, 18. https://doi.org/10.1186/s13229-015-0010-7

Mathew, N. E., Mallitt, K.-A., Masi, A., Katz, T., Walker, A. K., Morris, M. J., & Ooi, C. Y. (2022). Dietary intake in children on the autism spectrum is altered and linked to differences in autistic traits and sensory processing styles. *Autism Research, 15*(10), 1824–1839. https://doi.org/10.1002/aur.2798

Mayer, E. A., Nance, K., & Chen, S. (2022). *The gut–brain axis*. *Annual Review of Medicine, 73*, 439–453. https://doi.org/10.1146/annurev-med-042320-014032

Mazahery, H., Conlon, C. A., Beck, K. L., Mugridge, O., Kruger, M. C., Stonehouse, W., Camargo, C. A., Jr., Meyer, B. J., Tsang, B., Jones, B., & von Hurst, P. R. (2019).
A randomised controlled trial of vitamin D and omega-3 long chain polyunsaturated fatty acids in the treatment of core symptoms of autism spectrum disorder in children.
Journal of Autism and Developmental Disorders, 49(5), 1778–1794. https://doi.org/10.1007/s10803-018-3860-y

Meguid, N. A., Abdel Mawgoud, Y. I., Bjørklund, G., Anwar, M., Hashish, A. F., Sultan, M. A., Hemimi, M., & Gouda, A. S. (2022). Molecular characterization of probiotics and their influence on children with autism spectrum disorder. *Molecular Neurobiology, 59*(11), 6896–6902. https://doi.org/10.1007/s12035-022-02963-8

Młynarska, E., Barszcz, E., Budny, E., Gajewska, A., Kopeć, K., Wasiak, J., Rysz, J., & Franczyk, B. (2025). The gut–brain–microbiota connection and its role in autism spectrum disorders. *Nutrients, 17*(7), 1135. https://doi.org/10.3390/nu17071135

Mulyani, N. S., Arnisam, A., Andriani, A., Fitrianingsih, E., Hadi, A., & Al Rahmad, A. H. (2023). The effect of nutrition counseling on mother's knowledge and nutrition information in autistic children in Banda Aceh City. *Open Access Macedonian Journal of Medical Sciences, 11*(E), E236–E241. https://doi.org/10.3889/oamjms.2023.9573

Nimbley, E., Golds, L., Sharpe, H., Gillespie-Smith, K., & Duffy, F. (2022). Sensory processing and eating behaviours in autism: A systematic review. *European Eating Disorders Review, 30*(5), 538–559. https://doi.org/10.1002/erv.2920

Nitschke, A., Deonandan, R., & Konkle, A. T. M. (2020). *The link between autism spectrum disorder and gut microbiota: A scoping review*. *Autism, 24*(6), 1328–1344. https://doi.org/10.1177/1362361320913364

Padmanabhan, P. S. S., & Shroff, H. (2022). Mealtime behaviors in ASD schools. *International Journal of Developmental Disabilities, 68*(2), 198–206. https://doi.org/10.1080/20473869.2020.1738794

Patil, O., & Kaple, M. (2023). Sensory processing in autism spectrum disorder: A review. *Cureus, 15*(10), e48020. https://doi.org/10.7759/cureus.48020

Rochedy, A. (2018). Autismes et socialisations alimentaires: Particularités alimentaires des enfants avec un trouble du spectre de l'autisme et ajustements parentaux pour y faire face. *Alter: European Journal of Disability Research, 12*(1), 45–60. https://doi.org/10.1016/j.alter.2017.10.001

Saad, K., Shabaan, I., Hassan, A. M. M., Ezzat, M., Abouzed, M. A., Hamed, Y., Ibrahim, M. F. M., & Gad, E. F. (2024). Gluten-free, casein-free diet for children with autism spectrum disorder: A case-controlled study. *Journal of Pharmacy and Bioallied Sciences, 16*(Suppl. 1), S905–S908. https://doi.org/10.4103/jpbs.jpbs_1074_23

Santocchi, E., Guiducci, L., Prosperi, M., Calderoni, S., Gaggini, M., Apicella, F., Tancredi, R., Billeci, L., Mastromarino, P., Grossi, E., Gastaldelli, A., Morales, M. A., & Muratori, F. (2020). Effects of probiotic supplementation on gastrointestinal, sensory and core symptoms in autism spectrum disorders: A randomized controlled trial. *Frontiers in Psychiatry, 11*, 550593. https://doi.org/10.3389/fpsyt.2020.550593

Soleimanpour, S., Abavisani, M., Khoshrou, A., & Sahebkar, A. (2024). Probiotics for autism spectrum disorder: An updated systematic review and meta-analysis of effects on symptoms. *Journal of Psychiatric Research, 179*, 92–104. https://doi.org/10.1016/j.jpsychires.2024.09.009

Woods, S., Doherty, A., & Hill, J. (2024). *Dietary interventions in autism: A critical appraisal and commentary on the findings of a systematic review*. *British Journal of Neuroscience Nursing, 20*(4), 142–147. https://doi.org/10.12968/bjnn.2024.0035

Wu, Y., & Su, Q. (2024). *Harnessing the gut microbiome: To what extent can pre-/probiotics alleviate immune activation in autism spectrum disorder? Nutrients, 16*(15), 2382. https://doi.org/10.3390/nu16152382

Zafirovski, K., Trpevska Aleksoska, M., Thomas, J., & Hanna, F. (2024). Impact of gluten-free and casein-free diet on behavioural outcomes and quality of life of autistic children and adolescents: A scoping review. *Children, 11*(7), 862. https://doi.org/10.3390/children11070862

Zhang, Z., Kang, W., Mi, Y., Zhong, X., & He, Y. (2025). The microbiota–gut–brain axis in autism: Associations, causal inference, and interventions—A narrative review. *Pathogens, 14*(11), 1145. https://doi.org/10.3390/pathogens14111145