



Review Article

The Synbiotic Potential of GOS and *Lactobacillus reuteri* in Improving Gut Comfort and Supporting Brain, Bone and Muscle Development

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Abstract

The initial years of childhood is a crucial stage of development marked by rapid growth and maturation of the gastrointestinal system and immune function, brain growth, and establishment of musculoskeletal function. During this period, nutrition plays a fundamental role not only by providing essential nutrients but also by shaping the gut microbiota, which acts as an important regulator of digestion, metabolism, immunity, and systemic development. Increasing evidence highlights the potential of synbiotic nutrition, combining prebiotics and probiotics, as an effective strategy for maintaining a favorable intestinal environment while promoting broader developmental outcomes. Among commonly studied prebiotic compounds, galacto-oligosaccharides (GOS) have received considerable attention for their role in shaping intestinal microbial communities. They selectively stimulate beneficial intestinal microorganisms, particularly *Bifidobacterium*, promoting microbial balance while encouraging bacterial fermentation processes that generate health-supporting compounds, including SCFAs. *Lactobacillus reuteri* is a beneficial bacterial strain naturally present in the gastrointestinal tract and contributes to gut homeostasis through microbial competition, antimicrobial activity, immune modulation, and support for the structural and functional integrity of the intestinal lining. The combined biological effects produced when GOS is used together with *L. reuteri* create a synbiotic environment that supports better gastrointestinal tolerance and normal intestinal maturation. Beyond gastrointestinal benefits, a growing body of research indicates that intestinal microbial communities may have effects extending beyond the digestive system, involving multiple organ systems through complex communication networks, including the gut-brain axis, gut-bone axis, and gut-muscle axis. Microbial metabolites, immune mediators, and improved nutrient utilization may contribute to neurological maturation, cognitive development, bone mineralization, and muscle growth.

Keywords

Synbiotic, Galacto-oligosaccharides (GOS), *Lactobacillus Reuteri*, Gut Microbiota, Gut-brain Axis, Gut-bone Axis, Gut-muscle Axis, Digestive Comfort

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1. Introduction

Early childhood is a period of rapid biological transformation, during which multiple physiological systems including the gastrointestinal tract, immune system, nervous system, skeletal system, and muscular system undergo continuous maturation. Adequate nutrition during this stage provides essential substrates for growth while also influencing biological processes involved in digestion, microbiota development, immunity, and organ function [1].

The gastrointestinal tract is increasingly recognized as a central regulator of early-life health. The intestinal microbiota represents a dynamic ecosystem containing trillions of microorganisms that interact with dietary components and host physiology. These microbial communities contribute to digestion, nutrient metabolism, intestinal barrier maintenance, immune maturation, and communication with distant organs [2].

During infancy, gastrointestinal discomforts such as colic, regurgitation, irregular stool patterns, and feeding intolerance are commonly observed due to immature digestive function and ongoing microbiome development. Supporting a balanced intestinal environment may therefore contribute to improved digestive comfort and feeding tolerance.

Prebiotics and probiotics are increasingly used in infant nutrition because of their potential to support a healthy gut environment. Prebiotics are specific dietary substances that are utilized by beneficial microorganisms and help encourage their growth and activity. Probiotics, in contrast, are live microorganisms that can produce health benefits when taken in sufficient amounts. When these two components are used together, they are referred to as synbiotics, which are designed to enhance microbial balance by combining beneficial microorganisms with the nutrients that help sustain their growth and function [3].

Galacto-oligosaccharides (GOS) are among the most studied prebiotic ingredients in early-life nutrition. Similar to certain oligosaccharides naturally found in human milk, GOS resist digestion in the upper gastrointestinal tract and reach the colon, where they selectively stimulate beneficial bacterial populations, particularly bifidobacteria. Systematic reviews of

infant nutrition studies have shown that prebiotic and synbiotic interventions can increase fecal *Bifidobacterium* levels and may influence stool characteristics and gastrointestinal tolerance [4].

Lactobacillus reuteri is one of the extensively studied probiotic strains in infant nutrition. It supports intestinal microbial balance through competitive exclusion of undesirable microorganisms, production of antimicrobial compounds such as reuterin, modulation of immune responses, and maintenance of intestinal homeostasis. Studies investigating *L. reuteri* DSM 17938 have reported potential benefits in selected gastrointestinal conditions, including infantile colic, although outcomes depend on strain specificity and population characteristics [5].

Recent research has expanded the importance of gut-directed nutrition beyond digestive health by highlighting communication between the gut microbiota and other body systems. These interactions form the basis of the gut-brain axis, gut-bone axis, and gut-muscle axis, suggesting that microbiota modulation may influence neurological development, skeletal growth, and muscle function.

Therefore, the combination of GOS and *L. reuteri* represents a promising nutritional approach that may support not only gut comfort but also broader developmental outcomes during early childhood.

2. A Holistic Developmental Framework of Gut-Brain-Bone-Muscle Axis

The traditional concept of nutrition has focused mainly on supplying energy and essential nutrients for growth. However, current evidence suggests that nutrition also influences biological communication networks involving the gut microbiota and distant organs.

The Gut-Brain-Bone-Muscle Axis describes the interconnected relationship between intestinal microorganisms, metabolic pathways, immune regulation, and developmental processes [6].

Table 1. Gut-Brain-Bone-Muscle Communication Pathways [7].

Axis	Major Biological Pathways	Potential Developmental Outcomes
Gut-Brain Axis	Microbial metabolites, SCFAs, neurotransmitters, immune signaling, neuroendocrine pathways	Brain maturation, cognitive function, emotional regulation
Gut-Bone Axis	Mineral absorption, vitamin metabolism, SCFAs, inflammatory regulation	Bone mineralization and skeletal growth
Gut-Muscle Axis	Nutrient utilization, metabolic regulation, protein metabolism, inflammation control	Muscle growth, strength, and physical development

2.1. Microbiota Communication with the Developing Brain [8]

The gut and brain communicate through multiple pathways involving:

- 1) Microbial metabolites
- 2) Short-chain fatty acids (SCFAs)
- 3) Immune mediators
- 4) Vagus nerve signaling
- 5) Neurotransmitter-related pathways

Beneficial intestinal microorganisms may influence brain development by regulating inflammation, supporting intestinal barrier function, and producing metabolites involved in neurological signaling.

During early childhood, when the brain undergoes rapid neurodevelopment, maintaining a balanced microbiota may contribute to optimal neurological maturation.

2.2. Microbiota and Skeletal Development with Gut-Bone Axis

Bone development requires adequate availability of minerals, proteins, vitamins, and growth-related signals. The gut microbiota may influence skeletal development through:

- 1) Improved nutrient absorption
- 2) Calcium and mineral availability
- 3) Regulation of inflammatory pathways
- 4) Production of microbial metabolites

A healthy intestinal environment may therefore contribute indirectly to bone formation and mineralization [9].

3. Biological Mechanisms of GOS and *Lactobacillus reuteri* in Early-Life Development

The beneficial effects of synbiotic nutrition arise from the complementary actions of prebiotics and probiotics. While prebiotics provide substrates that selectively support beneficial microorganisms, probiotics contribute specific functional activities that influence microbial balance, intestinal physiology, and host responses. The combination of GOS and *Lactobacillus reuteri* provides a synergistic approach by creating a favorable intestinal environment while delivering targeted microbial benefits [10].

3.1. Galacto-Oligosaccharides (GOS): A Prebiotic Foundation for Gut Health

Galacto-oligosaccharides (GOS) are non-digestible carbohydrates that reach the colon intact, where they are

selectively fermented by beneficial bacteria. Their structure resembles certain oligosaccharides naturally present in human milk, allowing them to function as substrates that support the development of a beneficial infant gut microbiota [11].

Biological functions of GOS:

- 1) Selectively stimulates beneficial bacteria, particularly *Bifidobacterium*
- 2) Promotes microbial diversity and balance
- 3) Enhances production of short-chain fatty acids (SCFAs)
- 4) Supports intestinal barrier integrity
- 5) Contributes to immune system maturation

The fermentation of GOS by beneficial microorganisms produces SCFAs, including acetate, propionate, and butyrate. These metabolites provide energy for intestinal epithelial cells, support gut barrier function, and influence immune regulation [12].

Table 2. Biological Actions of GOS [13].

Function of GOS	Biological Mechanism	Potential Benefit
Prebiotic activity	Selective bacterial fermentation	Increased beneficial bacteria
SCFA production	Microbial fermentation pathway	Improved intestinal environment
Gut barrier support	Enhanced epithelial function	Better digestive tolerance
Microbial modulation	Increased beneficial bacterial populations	Balanced gut ecosystem

3.2. *Lactobacillus reuteri*: A Probiotic Modulator of Gut Homeostasis [14]

Lactobacillus reuteri is a well-characterized probiotic strain naturally associated with the human gastrointestinal tract. It contributes to intestinal health through interactions with both microbial communities and host biological systems.

Biological functions of *L. reuteri*:

- 1) Helps maintain a balanced intestinal microbial community
- 2) Restricts the growth of potentially harmful microorganisms
- 3) Produces antimicrobial substances, including reuterin
- 4) Strengthens and maintains intestinal barrier integrity
- 5) Regulates immune system responses and activity

Through these mechanisms, *L. reuteri* may contribute to improved gastrointestinal tolerance and digestive comfort during infancy [15].

Table 3. Functional Benefits of *L. reuteri*.

Mechanism	Biological Action	Developmental Benefit
Microbial competition	Limits undesirable bacterial growth	Maintains microbial balance
Antimicrobial activity	Production of reuterin	Supports gut protection
Immune modulation	Regulates inflammatory responses	Promotes gut homeostasis
Barrier support	Maintains intestinal integrity	Improved digestive tolerance

3.3. The Synbiotic Synergy of GOS and *L. reuteri* [16]

The combination of GOS and *L. reuteri* creates a

complementary relationship where the prebiotic component supports the survival and activity of beneficial microorganisms, while the probiotic component provides targeted microbial functions.

The proposed mechanism can be summarized as:

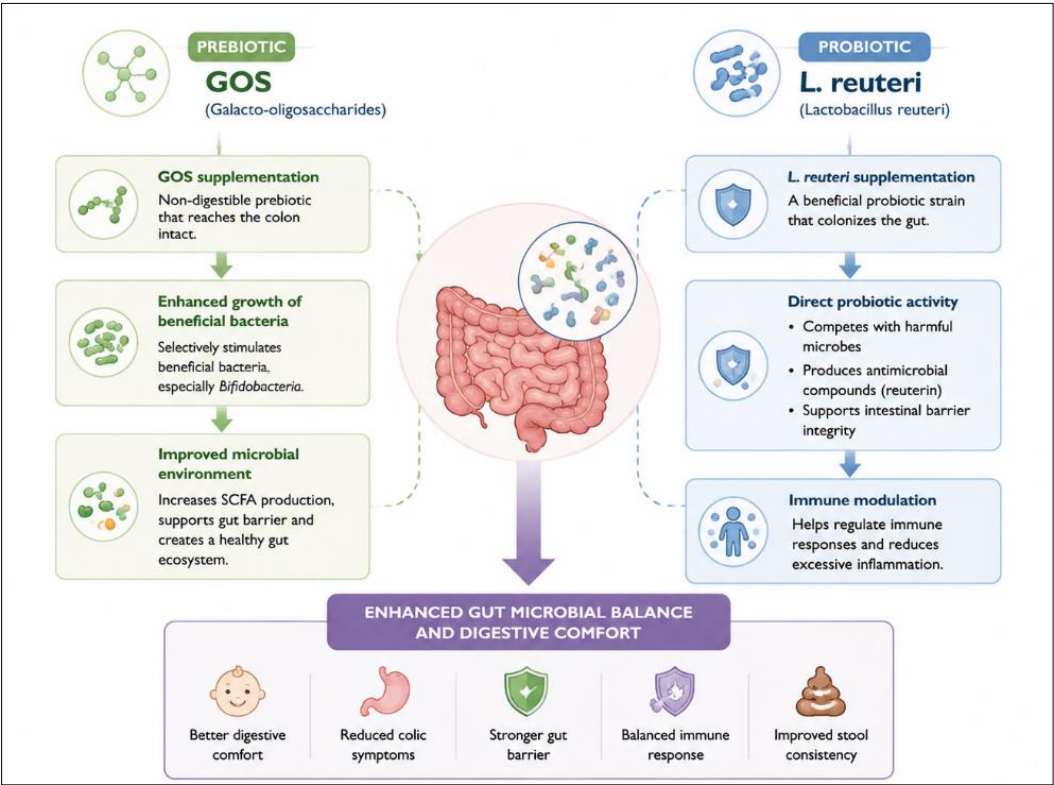


Figure 1. Synbiotic Synergy of GOS and *L. reuteri* [17].

Table 4. Complementary Roles of GOS and *L. reuteri*.

Component	Primary Role	Contribution
GOS	Prebiotic substrate	Supports beneficial bacterial growth
<i>L. reuteri</i>	Probiotic microorganism	Provides targeted microbial effects
Combined synbiotic action	Microbiota optimization	Supports digestive and developmental outcomes

4. Advancing Gut Comfort Through Synbiotic Benefits of GOS and *L. reuteri* [18]

Digestive comfort is a fundamental component of infant wellbeing. During early life, the gastrointestinal tract undergoes continuous maturation, and temporary digestive challenges such as colic, regurgitation, and stool irregularities are commonly observed.

Supporting a balanced gut microbiota may improve gastrointestinal adaptation and contribute to better feeding tolerance.

4.1. Supporting Infant Colic and Digestive Discomfort [19]

Infant colic is characterized by excessive crying and discomfort without an identifiable medical cause. Alterations in intestinal microbiota composition, intestinal motility, and inflammatory responses have been proposed as contributing factors.

Potential mechanisms through which *L. reuteri* may support colic-related comfort include:

- 1) Modulation of intestinal microbiota
- 2) Improvement of gut motility
- 3) Reduction of intestinal inflammatory responses
- 4) Enhancement of digestive adaptation

Clinical studies involving *L. reuteri* DSM 17938 have demonstrated potential benefits in reducing crying duration associated with infantile colic, particularly among breastfed infants. However, probiotic effects are strain-specific and may vary according to population and clinical conditions [20].

4.2. Sustaining Regurgitation and Feeding Tolerance [21]

Regurgitation is frequently observed in infants because of the incomplete maturation of the gastrointestinal system. Nutritional approaches that promote digestive development may help enhance feeding tolerance and overall gastrointestinal comfort.

Possible mechanisms include:

- 1) Enhanced intestinal microbial balance
- 2) Enhanced gastrointestinal function
- 3) Better adaptation to feeding patterns

By supporting a healthier intestinal environment, synbiotic nutrition may contribute to overall digestive comfort.

4.3. Supporting Stool Consistency and Bowel Comfort [22]

Prebiotic fibers such as GOS influence stool characteristics

through microbial fermentation and increased water retention within the intestinal environment.

Potential benefits include:

- 1) Improved stool consistency
- 2) Increased bowel comfort
- 3) Enhanced intestinal function
- 4) Support for regular bowel patterns

These outcomes are linked to enhanced activity and growth of beneficial microorganisms in the colon.

5. Gut Microbiota Communicates With The Developing Brain Through Multiple Biological Pathways [23]

The gut microbiota communicates with the developing brain through multiple biological pathways, including microbial metabolites, immune signaling, hormonal regulation, and neural pathways.

Table 5. Gut-Brain Communication Pathways.

Pathway	Biological Mechanism	Potential Effect
SCFAs	Microbial metabolites influencing immune and neural pathways	Supports brain environment
Immune signaling	Regulation of inflammatory mediators	Supports neurodevelopment
Neuroactive compounds	Microbial influence on neurotransmitter pathways	Brain function regulation
Gut hormones	Interaction with metabolic pathways	Developmental signaling

During early childhood, when neural networks are rapidly developing, maintaining a balanced microbiota may support optimal neurological maturation.

Potential developmental implications include:

- 1) Support of neuroimmune development
- 2) Regulation of stress responses
- 3) Improved metabolic communication between gut and brain

6. Advancing Healthy Bone Development Through the Gut-Bone Axis

Bone growth during childhood requires adequate calcium, vitamin D, protein, and other essential nutrients. The intestinal microbiota may influence skeletal development by affecting nutrient absorption and systemic metabolic regulation.

Table 6. Gut-Bone Development Pathway.

Gut Function	Biological Mechanism	Bone Outcome
Improved nutrient absorption	Increased mineral availability	Bone mineralization
SCFA production	Metabolic signaling	Bone remodeling support
Immune regulation	Reduced inflammatory activity	Healthy skeletal development
Microbial metabolites	Influence on bone pathways	Growth support

Synbiotic nutrition may support bone development indirectly by promoting a healthier gut environment that enhances nutrient absorption and improves the utilization of essential growth-related nutrients.

7. Supporting Muscle Development Through the Gut-Muscle Axis

Muscle growth depends on sufficient protein utilization, energy balance, and proper regulation of growth-related

pathways. The gut microbiota may contribute to muscle development by improving nutrient availability and influencing metabolic processes.

Potential mechanisms include:

- 1) Improved nutrient absorption
- 2) Enhanced protein utilization
- 3) Regulation of metabolic pathways
- 4) Reduction of excessive inflammation

Emerging evidence suggests that microbiota-targeted nutrition may contribute to functional growth outcomes during early childhood.

Table 7. Gut-Muscle Communication Pathway [24].

Gut Influence	Mechanism	Muscle Outcome
Nutrient utilization	Improved availability of growth nutrients	Muscle development
Metabolic regulation	Energy balance support	Muscle function
Reduced inflammation	Improved tissue environment	Healthy muscle growth

8. Synbiotic Nutrition as a Modulator of Early-Life Gut Microbiota Development

The first years of life represent a critical period when the gastrointestinal microbiota, immune system, brain, bone, and muscle undergo rapid development. Increasing evidence indicates that the gut microbiota acts as an important biological mediator connecting nutrition with multiple developmental processes. The concept of the Gut-Brain-Bone-Muscle Axis provides a broader understanding of how dietary interventions targeting the intestinal environment may influence whole-body development [25].

The combination of galacto-oligosaccharides (GOS) and *Lactobacillus reuteri* represents a promising synbiotic approach because it provides complementary functions. GOS acts as a selective substrate that supports beneficial

microorganisms, while *L. reuteri* provides specific probiotic activities that contribute to microbial balance, intestinal barrier function, and immune regulation.

8.1. Synbiotic Nutrition and Gut Microbiota Development [26]

The establishment of the infant gut microbiota is influenced by multiple factors, including mode of delivery, feeding practices, environment, and dietary exposure. A balanced microbiota during early life is associated with improved intestinal function and immune maturation.

GOS contributes to microbiota development by:

- 1) Increasing beneficial bacterial populations, particularly *Bifidobacterium*
- 2) Supporting microbial diversity
- 3) Enhancing production of beneficial metabolites
- 4) Promoting intestinal ecosystem stability

Meanwhile, *L. reuteri* contributes through:

- 1) Colonization and interaction with intestinal

microorganisms

- 2) Production of antimicrobial compounds
- 3) Regulation of inflammatory pathways
- 4) Support of intestinal homeostasis

Together, GOS and *L. reuteri* create a favorable microbial environment that supports digestive health and may influence broader developmental pathways [27].

8.2. Advancing Gut Comfort Through GOS and *L. reuteri* [28]

Digestive discomfort is a common concern during infancy due to gastrointestinal immaturity and ongoing microbiome development. Symptoms such as colic, regurgitation, and irregular stool patterns may affect feeding experience and parental wellbeing.

Synbiotic nutrition may support gut comfort through several mechanisms:

8.2.1. Microbiota Balance

GOS promotes beneficial bacterial growth, while *L. reuteri* contributes targeted probiotic effects, helping maintain a balanced intestinal ecosystem.

8.2.2. Improved Gut Barrier Function

A healthy intestinal barrier reduces excessive immune activation and supports normal digestive function.

8.2.3. Regulation of Intestinal Environment

Microbial metabolites such as SCFAs contribute to intestinal health by supporting epithelial function and regulating inflammatory responses.

Clinical studies with *L. reuteri* DSM 17938 have demonstrated potential benefits in reducing symptoms associated with infantile colic, although outcomes depend on probiotic strain, dosage, and infant characteristics.

8.3. Gut-Brain Communication and Neurodevelopment

The gut-brain axis represents a complex communication network between intestinal microorganisms and the developing nervous system.

Several pathways contribute to this interaction:

Table 8. Gut-Brain Communication and Neurodevelopment.

Communication Pathway	Biological Role
Microbial metabolites	Influence immune and neurological signaling
Short-chain fatty acids	Support intestinal and systemic metabolic regulation

Communication Pathway	Biological Role
Immune pathways	Regulate inflammatory responses
Neuroendocrine signaling	Connect gut function with brain processes

During early childhood, brain development involves rapid neuronal growth, synapse formation, and functional maturation. Although direct evidence linking specific synbiotics to cognitive outcomes remains an emerging area, maintaining a healthy gut environment may provide supportive conditions for optimal neurodevelopment.

Potential mechanisms include:

- 1) Supporting neuroimmune balance
- 2) Maintaining metabolic homeostasis
- 3) Influencing communication between gut and nervous system

8.4. Gut-Bone Connection and Skeletal Development [29]

Bone development during childhood requires continuous availability of calcium, phosphorus, vitamin D, protein, and other essential nutrients. The intestinal microbiota may influence skeletal development by affecting nutrient absorption and metabolic regulation.

Potential mechanisms include:

8.4.1. Enhanced Mineral Utilization

A healthy intestinal environment may improve availability and absorption of minerals required for bone formation.

8.4.2. SCFA-Mediated Effects

Microbial metabolites may influence systemic metabolic pathways involved in bone remodeling.

8.4.3. Immune Regulation

Balanced immune activity may support a favorable environment for skeletal growth.

The gut-bone axis highlights the importance of considering intestinal health as part of a comprehensive approach to supporting healthy bone development.

8.5. Gut-Muscle Connection and Functional Growth

Muscle development requires adequate protein availability, energy metabolism, and coordinated growth signaling. Emerging research suggests that the gut microbiota may contribute to muscle development through nutrient utilization and metabolic regulation.

Potential pathways include:

- 1) Improved digestion and nutrient absorption
- 2) Regulation of energy metabolism
- 3) Influence on inflammatory pathways

- 4) Support of muscle protein utilization

A healthy gut environment may therefore contribute indirectly to physical growth and functional development [30].

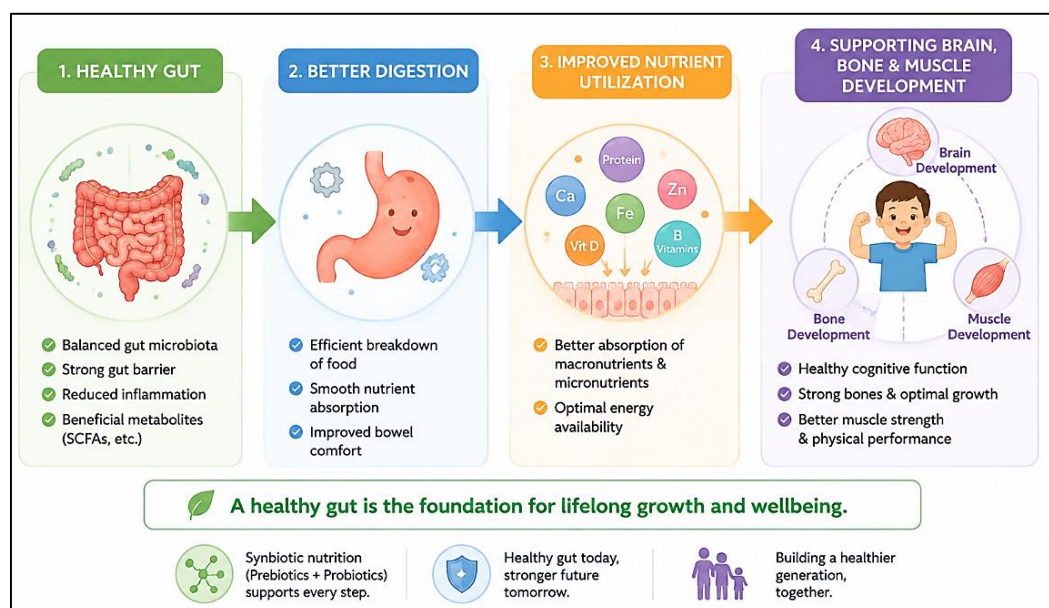


Figure 2. The Gut Growth Connection [31].

9. Conclusion

The gut microbiota plays a fundamental role in early childhood health by affecting physiological processes that extend beyond digestion. The synbiotic combination of GOS and *Lactobacillus reuteri* offers combined benefits by encouraging the growth of beneficial microorganisms, supporting microbial balance, and enhancing digestive well-being.

GOS acts as a prebiotic component that selectively supports beneficial bacterial populations and promotes the generation of microbial metabolites, whereas *L. reuteri* provides probiotic effects through regulation of microbial communities, immune response modulation, and maintenance of intestinal stability. Together, these components establish a favorable gut environment that supports healthy growth and development during early life.

Emerging evidence suggests that the benefits of synbiotic nutrition may extend beyond gut health through interconnected communication pathways including the gut-brain axis, gut-bone axis, and gut-muscle axis. Through improved nutrient utilization, metabolic regulation, and immune balance, gut-directed nutritional strategies may contribute to optimal brain maturation, healthy bone development, and muscle growth.

While further research is required to establish long-term developmental outcomes, current evidence supports the importance of considering gut microbiota as an integral

component of early-life nutrition. A holistic approach combining digestive health with broader developmental goals may help healthcare professionals support infants and young children in achieving healthy growth trajectories and lifelong wellbeing.

Author Contributions

Swapan Kumar Halder: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Alomgir Hossain: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft

Faisal Hasan: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Visualization

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Belfar Hossain: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Moin Uddin Talukder: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration

Conflicts of Interest

The authors declare no conflicts of interest.

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