

Review

Understanding Stunting: Impact, Causes, and Strategy to Accelerate Stunting Reduction—A Narrative Review

Aisyah Tri Mulyani ¹, Miski Aghnia Khairinisa ², Alfi Khatib ³ and Anis Yohana Chaerunisaa ^{4,*}

¹ Magister Program, Faculty of Pharmacy, University of Padjadjaran, Jalan Raya Bandung Sumedang km 21 Jatinangor, Sumedang 45363, Indonesia; aisyah17015@mail.unpad.ac.id

² Department of Pharmacology and Clinical Pharmacy, Faculty of Pharmacy, University of Padjadjaran, Jalan Raya Bandung Sumedang km 21 Jatinangor, Sumedang 45363, Indonesia; miski.aghnia@unpad.ac.id

³ Department of Pharmaceutical Chemistry, Faculty of Pharmacy, International Islamic University Malaysia (IIUM), Kuantan 25200, Pahang, Malaysia; alfikhatib@iium.edu.my

⁴ Department of Pharmaceutics and Pharmaceutical Technology, Faculty of Pharmacy, University of Padjadjaran, Jalan Raya Bandung Sumedang km 21 Jatinangor, Sumedang 45363, Indonesia

* Correspondence: anis.yohana.chaerunisaa@unpad.ac.id; Tel.: +62-813-9529-2203

Abstract: Stunting is a major global health concern, particularly in low- and middle-income countries, due to its persistently high prevalence. It often originates from chronic malnutrition during the critical first 1000 days of life. Maternal and child nutrition are critical determinants of a child's growth and development. This article aimed to explore the impact, causes, and evidence-based strategies to accelerate the reduction of stunting incidence worldwide. This review was undertaken with sources from PubMed, Scopus, Google Scholar, Science Direct, and MEDLINE from October 2024 to January 2025. This review was undertaken with sources from PubMed, Scopus, Google Scholar, Science Direct, and MEDLINE from October 2024 to January 2025 using the keyword “Stunting”, “Causes of stunting”, “Stunting Impact”, “Stunting Intervention”, and “Stunting Prevention”. The findings highlight the multifactorial causes of stunting, including maternal malnutrition, inadequate breastfeeding and complementary feeding, poor sanitation, and socioeconomic factors. Stunting is associated with impaired linear growth, cognitive deficits, gut dysbiosis, endocrine disruption, anemia, and increased risk of chronic diseases later in life. Addressing stunting demands multisectoral strategies focusing on maternal and child nutrition, infection prevention, improved WASH (Water, Sanitation, and Hygiene) practices, and socioeconomic support. The evidence presented may guide policy development and targeted interventions to prevent stunting and its long-term effects.

Keywords: children; dysbiosis; growth failure; stunting; undernutrition



Academic Editor: Andrea Vania

Received: 30 March 2025

Revised: 21 April 2025

Accepted: 23 April 2025

Published: 29 April 2025

Citation: Mulyani, A.T.; Khairinisa, M.A.; Khatib, A.; Chaerunisaa, A.Y. Understanding Stunting: Impact, Causes, and Strategy to Accelerate Stunting Reduction—A Narrative Review. *Nutrients* **2025**, *17*, 1493. <https://doi.org/10.3390/nu17091493>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Stunting can be described as a condition where a child is significantly shorter than the expected height for their age. The WHO has a standard for measuring stunting in children, which is measured by the “Z score” assessment [1,2]. Stunting is a condition where a child's height-to-age ratio is less than two standard deviations (SDs) below the median value for their age, indicating potential limitations in the child's ongoing development. Globally, it is agreed to identify stunting by measuring the body length ratio of -2 SD against the age from the WHO median standard value, which is categorized as mild or moderate stunting. Meanwhile, children with a body length ratio of -3 SD against age from the WHO median standard value are categorized as having severe stunting [2,3]. Stunting in children begins from the early stages of life until the first three or four years [1,4,5]. The

first 1000 days of life are a crucial period for determining a child's future development, both in terms of physical and mental health [6–8]. Stunting syndrome can be identified as part of a continuous process cycle, starting from maternal nutrition during pregnancy, which is passed on to the child and continues into the next cycle through several factors, as explained in Figure 1 [9].

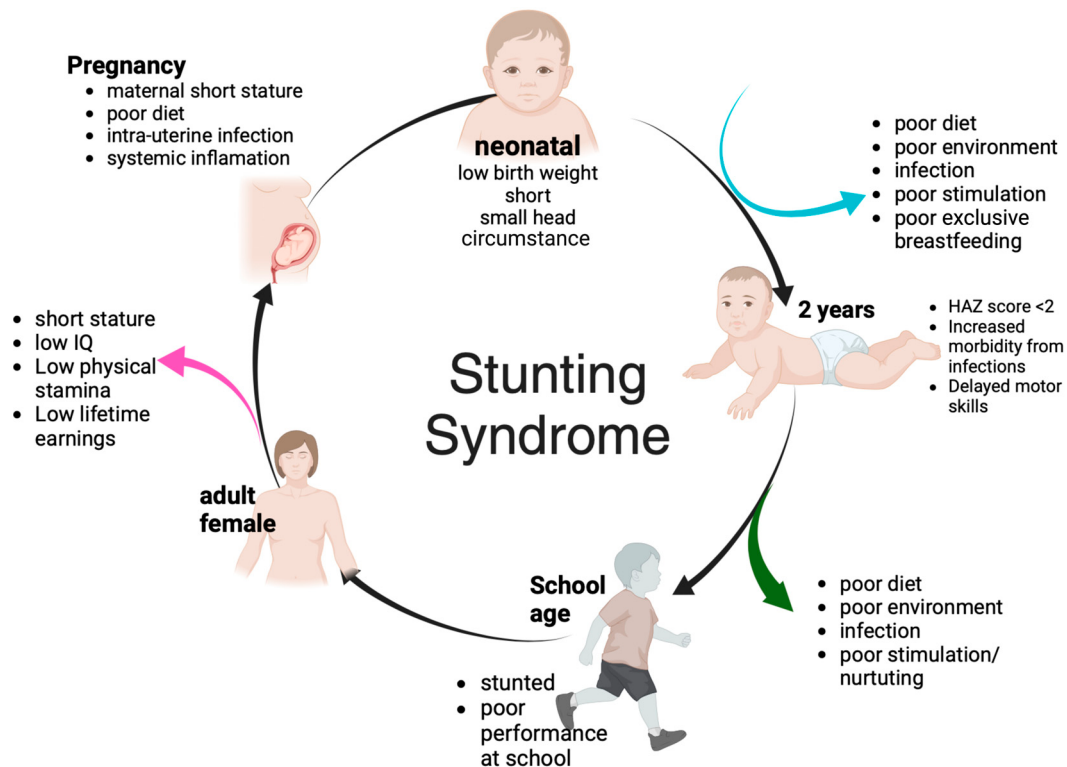


Figure 1. Stunting Syndrome: This figure explains how stunting syndrome is identified as a continuous cycle. Several factors that influence the intergenerational stunting syndrome cycle include genetic factors, nutritional deficiencies in mothers and children throughout life, inadequate breastfeeding, improper complementary feeding, infectious diseases and inflammation, and social factors such as lack of resources across generations and poverty. Various pathological alterations due to impaired linear growth in early life are associated with heightened morbidity and mortality rates, decreased physical ability, poor brain development, diminished economic prospects, and an increased risk of metabolic disorders in adulthood. HAZ—Height-for-Age Score (Created in BioRender, <https://www.biorender.com/>, accessed on 18 April 2025).

The causes of stunting, according to the conceptual framework proposed by the WHO, represent a complex and multifactorial issue. These factors include household conditions, inadequate complementary feeding, non-exclusive breastfeeding, infectious diseases, political economy, education, access to healthcare, social and cultural influences, environmental conditions, sanitation, and water quality [10]. Infant development is influenced by maternal nutrition, starting from pregnancy and continuing throughout breastfeeding. The WHO recommends exclusive breastfeeding until 2 years of age, followed by the gradual introduction of complementary foods starting at 6 months of age [11,12]. After reaching 6 months of age, children's energy and nutritional needs increase, so in addition to breastfeeding, complementary feeding is necessary to meet these additional energy and nutritional needs [13]. Poor maternal nutrition during pregnancy can limit fetal development and increase the consequences of stunting in children [14]. Inadequate complementary feeding involves insufficient food, excessive reliance on instant foods (often only mixed with water), using contaminated water, and storing food improperly in open spaces or unclean containers,

allowing bacteria to grow and potentially leading to infections in children [10]. In addition to inadequate nutrition, poor sanitation conditions in households can lead to prolonged exposure to environmental pathogens, resulting in alterations to the function and morphology of the gut microbiota, which potentially impair children's growth [15–17]. Poor household economic conditions, particularly low income, may exacerbate difficulties in affording nutritious food and accessing healthcare [8]. Stunting can lead to long-term effects such as diminished cognitive function, poor educational achievements, lower productivity, decreased earnings in adulthood, and an increased likelihood of chronic nutrition-related diseases in later life [18]. Despite a steady decline in its incidence, stunting remains a global issue. In 2022, UNICEF, the WHO, and The World Bank reported that 148.1 million children under the age of 5, representing 22.3% of this population, were affected by stunting. Although its incidence continues to decrease, further performance is needed to meet the target prevalence of 13.5% by 2030. The required global average annual reduction (AAR) to reach this target is 6.08%. Most children affected by stunting currently reside in Asia, accounting for 52% of the global total, and Africa, comprising 43% of the global total [19]. Thus, strategies from various sectors are essential to reduce the global burden of stunting. This article discussed the impacts of stunting, including growth failure, cognitive impairments, dysbiosis or enteric electrical dysfunction, endocrine system dysregulation, and anemia, while explaining the mechanisms contributing to these outcomes. Several studies investigating the relationship between the impacts of stunting are summarized in Appendix A, Table A1. Additionally, this article outlines strategies for preventing the impacts of stunting through targeted interventions aimed at reducing both the occurrence and consequences of stunting. A summary of general and specific strategies is presented in Appendix B, Table A2.

2. Methods of Search and Inclusion of Articles

Articles were searched on PubMed and Google Scholar, Scopus, and Science Direct, from October 2024 to January 2025. The websites of scientific organizations, such as the WHO, were also searched. The keywords were focused on defining: (1) the impact and consequences of stunting; (2) causes of stunting; (3) growth failure; (4) cognitive impairment; (5) gut microbiota; (6) dysbiosis; (7) anemia; (8) diabetes mellitus; (9) stunting intervention; (10) WASH; (11) SHINE; (12) stunting prevention. All studies were uploaded onto Mendeley's reference management platform, and identical references were removed.

The screening selection of articles was based on the main topic. The inclusion criteria were (1) classified as cohort study, cross-sectional study, case control study, randomized clinical trials, quasi-experimental study, and observational studies; (2) published between 1 January 2014 and 31 December 2024 in the English language; (3) stunting impact and consequences; (4) cause of stunting; (5) national strategy to accelerate stunting reduction. Exclusion criteria are as follows: articles in a language other than English; in vitro studies; animal studies; historical data; book.

3. Stunting Impact and Its Causes

3.1. Growth Failure

Nutrition provided to children directly impacts their growth and development from childhood through adulthood [20,21]. A child's growth is influenced by household conditions, family environment, infections, and dietary patterns [14,20]. Girls with stunting or of short stature (Height-for-Age Z-score < -2) had significantly lower intakes of calcium, β -carotene, riboflavin, niacin, zinc, iron, folic acid, and ascorbic acid than their counterparts with normal height according to a cross-sectional study conducted in India [22]. A meta-analysis revealed that children receiving nutrition enriched with multiple micronutrients

experienced a small but significant improvement in height, weight, and motor development. Energy, protein, and other nutrients are essential for promoting growth [23]. The mechanism by which nutritional intake affects growth is illustrated in Figure 2.

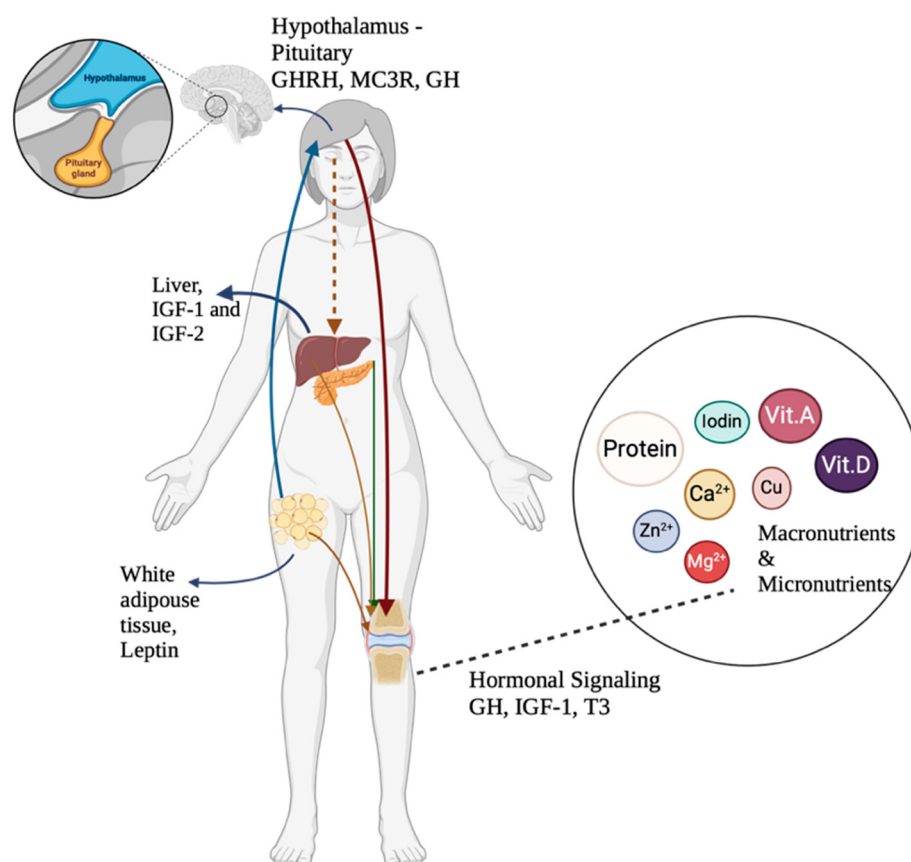


Figure 2. Explanation of the role of nutrition and endocrine regulation in stimulating growth. IGF-1—insulin-like growth factor 1; IGF-2—insulin-like growth factor 2; GH—growth hormone; GHRH—Growth Hormone Releasing Hormone; MC3R—Melanocortin-3 Receptor; T3—triiodothyronine; Ca^{2+} —calcium; Zn^{2+} —zinc; Mg^{2+} —magnesium; Cu—copper (Created in BioRender, <https://www.biorender.com/>, accessed on 3 December 2024).

As a key macronutrient, protein plays a crucial role in linear growth as it meets the metabolic demands of amino acids necessary for tissue development. Consuming protein can raise the levels of hormones such as insulin and insulin-like growth factor 1 (IGF-1), which promote endochondral ossification and enable longitudinal bone growth [24]. Restriction of protein consumption and reduced energy intake have significantly decreased IGF-1 levels in the body [25,26]. Under hypoglycemia or prolonged fasting conditions, resistance to growth hormone occurs peripherally, accompanied by a reduction in hepatic IGF-1 levels. The decrease in IGF-1 can induce protein catabolism by increasing amino acid levels in the gluconeogenesis pathway [24,27]. A peptide hormone called insulin-like growth factor 1 (IGF-1) promotes cell division, development, and proliferation and is essential for muscle hypertrophy [28,29]. This hormone is primarily synthesized in the liver in response to stimulation by growth hormone (GH) [30]. Apart from this regulating system, the liver and adipose tissue create fibroblast growth factor 21 (FGF-21), essential for metabolism and biological activities related to fatty acid oxidation, gluconeogenesis, and ketogenesis. In fasting states, FGF-21 levels are elevated in the liver, which in turn reduces growth hormone receptor expression and induces growth hormone resistance, as depicted in Figure 3. In addition, IGF-1 may exhibit diurnal fluctuations influenced by growth hormone secretion and feeding cycles. Nutritional deficiency can significantly disrupt the

chronobiology (daily rhythmic patterns) of IGF-1 by reducing IGF-1 production, disrupting the growth hormone–IGF-1 axis, altering circadian regulation, and having consequences for growth and development [31–33].

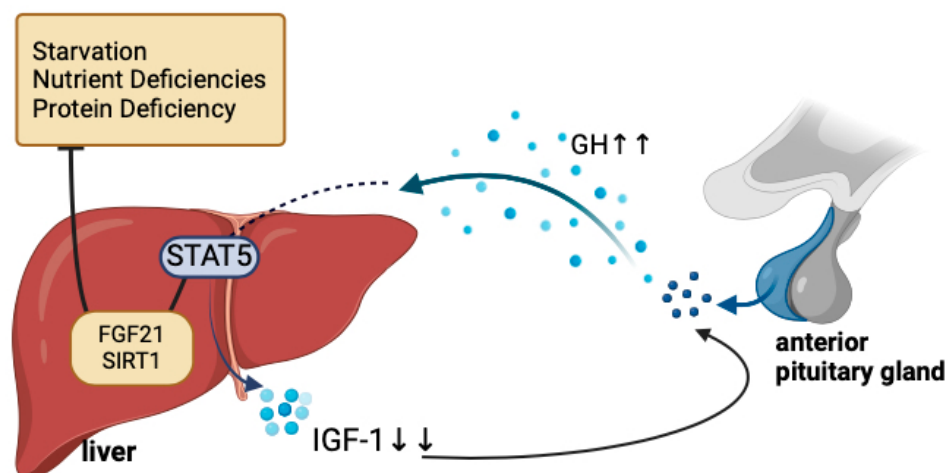


Figure 3. Mechanism of how fasting, nutrient deficiency, and protein deficiency affect growth hormones (GH, IGF-1, FGF21). IGF-1—insulin-like growth factor 1; GH—growth hormone; ↑—increase; ↓—decrease (Created in BioRender, <https://www.biorender.com/>, accessed on 23 December 2024).

Based on the explanation regarding the physiological factors of GH, IGF-I, and FGF21, it can be concluded that adequate nutrition can stimulate the combined actions of growth hormone (GH) and IGF-I during childhood and adolescence to promote long-term growth and somatic maturation. These adaptations may predispose individuals to a heightened sensitivity to IGF-1 oversecretion when exposed to overfeeding or excessive caloric intake in adulthood. The altered metabolic set points, established during childhood, may increase the risk of developing conditions such as obesity and cardiovascular diseases in adulthood, particularly under conditions of caloric excess that stimulate IGF-1 activity [34,35].

3.2. Cognitive Impairment

Children experiencing chronic stunting exhibit significantly lower cognitive abilities compared to normal children. Children with stunting are 3.6 times more likely to experience cognitive impairments than children without stunting [36,37]. The first 1000 days of life are a critical time for the growth and development of the brain. Adequate nutrition during pregnancy is essential for the optimal neurodevelopment of the infant. A cross-sectional study conducted in Pakistan found that stunted children exhibited impairments in language abilities and motor adaptation, which is consistent with other research suggesting that malnutrition adversely affects motor skills [38,39]. A diverse range of macronutrients and micronutrients is crucial for brain development. Carbohydrates, as a primary energy source, play a key role in cell metabolism and the formation of brain structures. Protein is involved in developing hippocampal structures, synaptogenesis (particularly essential amino acids), growth factor synthesis, cell proliferation, and differentiation. Additionally, fats are necessary for myelin synthesis, synapse formation, and the visual cortex. Vitamins and minerals, as micronutrients, also contribute significantly to cell metabolism, synaptic function, and myelin formation [40]. Iron plays a critical role in early brain development, particularly during the neonatal period and early childhood. Research has shown that iron deficiency during these stages is a key contributor to disturbances in cognitive development [41,42]. Thus, fats, vitamins, and minerals are indispensable for proper brain growth, especially during the early years. Deficiencies in any of these nutrients can negatively

affect cognitive, emotional, and motor development. Balanced nutrition is key to ensuring optimal brain health.

The consequences of stunting on cognitive function can be attributed to inadequate protein intake. Compared to their non-stunted counterparts, children with stunting have reduced levels of critical amino acids. Amino acids are necessary for synthesizing proteins and activating the mammalian target of rapamycin complex 1 (mTORC1) essential for developing numerous tissues, including myelination [43]. When amino acid levels are lowered, mTORC1 disperses in the cytosol and remains inactive. This inactive mTORC1 state may promote lipid synthesis while inhibiting myelination processes within the nervous system, leading to impaired cognition [43,44] (Figure 4).

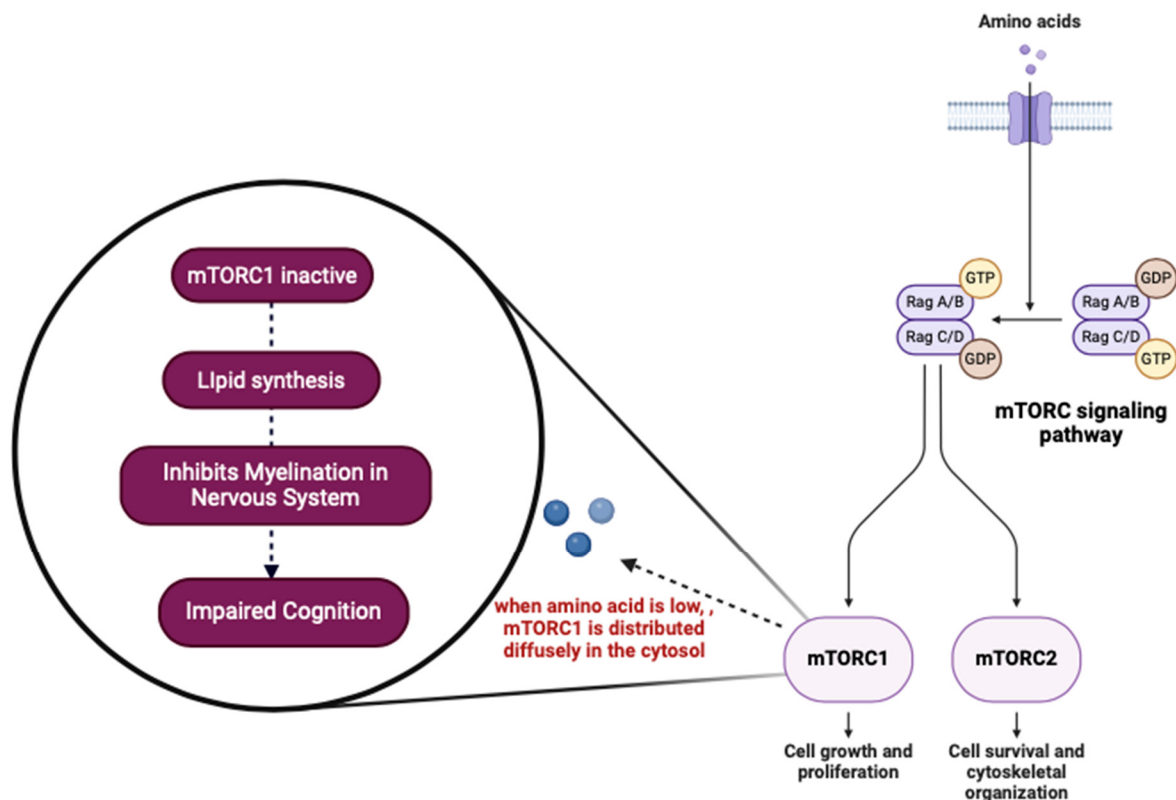


Figure 4. The role of amino acids in the mTORC pathway in inducing impaired cognition. mTORC—mammalian target of rapamycin; mTORC1—mammalian target of rapamycin complex 1; mTORC2—mammalian target of rapamycin complex 2; GDP—guanosine diphosphate; GTP—guanosine triphosphate; Rag—regulator proteins, Rag A/B is small rags, Rag C/D is large rags, while Rag A/B forms a heterodimer with product of Rag C/D (Created in BioRender, <https://www.biorender.com/>, accessed on 23 December 2024).

Stunting can also affect the structure and pathological function of the brain. Chronic malnutrition in the central nervous system can cause tissue damage, reduce synapses and synaptic neurotransmitters, inhibit myelination, and impair the development of dendritic branches during brain development [45]. Stunting and cognitive abilities are strongly associated with lasting effects contributing to poorer educational outcomes over time [46]. Thus, addressing stunting is an urgent public health priority, as early intervention is critical to prevent irreversible cognitive decline. Without timely action, the long-term impact on brain development can hinder a child's learning potential, academic performance, and future productivity, ultimately affecting both individual well-being and societal progress.

3.3. Dysbiosis (Infection, Enteric Environmental Dysfunction)

Stunting is caused by various factors, including intestinal infections and diarrheal diseases [47]. The gut microbiota refers to the collection of microorganisms, primarily bacteria, bacteriophages, fungi, yeasts, and other viruses such as protozoa and archaea, that form a complex ecosystem within the human digestive tract [48,49]. Dysbiosis is an imbalance in the gut microbiota composition caused by chronic consumption of enteric pathogens. These enteric pathogens activate the intestines' immune system, leading to localized and systemic inflammation. This condition affects the intestines' physiological and structural integrity, impairing the intestinal barrier's function and increasing permeability. This state is called enteric environmental dysfunction (EED), which can disrupt nutrient absorption, ultimately resulting in nutrient deficiencies in children [15]; this mechanism is illustrated in Figure 5.

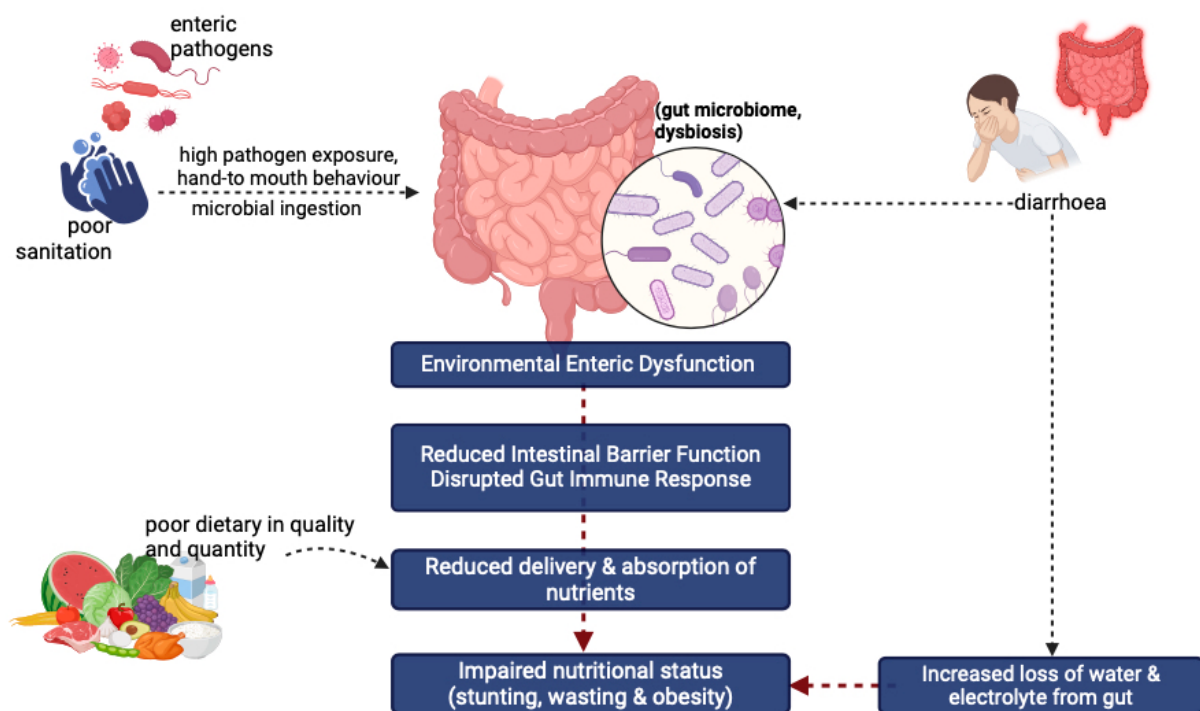


Figure 5. Pathophysiology EED induced impaired nutritional status (Created in BioRender, <https://www.biorender.com/>, accessed on 24 December 2024).

Several studies have shown that children with stunting display a distinctive gut microbiota conformation compared to their non-stunted counterparts. According to a long-term study in India, children with stunting had higher levels of *Desulfovibrio* spp. and lower levels of *Bifidobacterium longum* and *Lactobacillus mucosae* [50]. Stunted children exhibited higher levels of *Escherichia coli/Shigella* spp. and *Campylobacter* spp., while non-pathogenic microbiota was found in lower quantities [51]. Moreover, an increase in *Ruminococcus* groups 1 and 2, *Clostridium sensu stricto*, and *Collinsella* was noted in children with stunting, whereas no such changes were observed in non-stunted children [52]. Based on [53], children with stunting have reduced levels of *Prevotella* 9, which is prevalent in children with appropriate nutritional conditions. Dysbiosis has been associated with reduced short-chain fatty acids (SCFAs) production, increased intestinal permeability, and an elevated susceptibility to infections. Micronutrient metabolism and bioavailability may be impacted by alterations in intestinal barrier function brought on by the microbiome. These procedures may impair intestinal function and restrict children's ability to grow normally [54]. Zinc homeostasis, the process by which the body maintains a stable zinc

level, is primarily regulated through intestinal absorption. A study has demonstrated that a significant portion of dietary zinc intake, approximately 20%, is utilized by the gut microbiota. Another study also revealed that zinc deficiency caused the alteration of the gut microbiota and their functional capacity [55,56]. A global study has shown that diarrheal diseases cause stunting problems in many developing countries [57]. Stunting is also associated with inadequate drinking water sources and poor sanitation facilities. Poor household hygiene practices, such as ineffective handwashing to reduce exposure to enteric pathogens, can lead to diarrhea or inflammation in the digestive tract [58]. In summary, timely intervention in cases of stunting is crucial to prevent dysbiosis, as prolonged undernutrition can disrupt the gut microbiota, weakening immune function and impairing nutrient absorption. Managing stunting early supports healthy growth and development and helps maintain a balanced gut ecosystem essential for long-term health.

3.4. Endocrine Dysregulation

3.4.1. Hypothyroid

Iodine is a vital micronutrient necessary for the synthesis of thyroid hormones, thyroxine (T4), and triiodothyronine (T3), which are essential during pregnancy to support the developmental requirements of the fetal nervous system [59]. Iodine needs to increase by over 50% during pregnancy. Insufficient iodine intake during pregnancy can lead to maternal and fetal hypothyroidism. Research has shown the consequences of iodine deficiency based on its timing and severity, with the most severe consequence being cretinism [60]. A deficiency in thyroid hormones, or hypothyroidism, can lead to functional and metabolic disorders that interfere with overall growth and development, a condition known as iodine deficiency disorder (IDD) [61]. The pituitary gland releases thyroid-stimulating hormone (TSH) after receiving a thyrotropin-releasing hormone (TRH) from the brain's hypothalamus. TSH binds to TSH receptors on thyroid follicular cells. Iodine from consumed food is absorbed into the thyroid gland and stored as iodide (I^-). The enzyme thyroid peroxidase (TPO) oxidizes this iodide into its active form. The oxidized iodine binds with its precursor protein, thyroglobulin, produced by thyroid follicular cells in a process known as thyroglobulin iodination. This iodination forms monoiodotyrosine (MIT) and diiodotyrosine (DIT). The coupling process then forms the main thyroid hormones, thyroxine (T4) and triiodothyronine (T3). The thyroid gland releases these hormones into the bloodstream, controlling several bodily functions, such as energy metabolism, growth and development, and body temperature regulation [62]. The stages of thyroid hormone formation are depicted in Figure 6.

However, in the case of malnutrition experienced by children with stunting, the regulation of thyroid hormone formation necessary for growth becomes impaired. This represents an adaptive mechanism of endocrine dysregulation, as illustrated in Figure 7. A study reviewing iodine deficiency disorders (IDDs) as a predictor of stunting demonstrated, through a logistic regression model, that students with clinical goiter and urinary iodine concentration (UIC) below 17 $\mu\text{g/L}$ were associated with stunting [63]. Another study revealed that the occurrence of hypothyroidism in infants before birth could affect cognitive abilities, primarily due to hippocampal dysfunction [64]. A study examining the relationship between hypothyroid mice and cognitive function, using mice induced with 5 or 50 ppm propylthiouracil (PTU) in drinking water from day 14 to day 21 post-birth, showed that hypothyroid mice exhibited cognitive impairment. This was evidenced by the OLT (object location test) discrimination ratio, which was significantly altered in the PTU-induced group compared to the control group. Furthermore, this study reported a reduction in neurotransmitter levels (glutamate, γ -aminobutyric acid, and glycine) in the hippocampus, as measured by in vivo microdialysis during OLT testing. Thus, the

disruption of neurotransmitter secretion can cause hippocampal dysfunction and persist into adulthood [65]. Thyroid hormones play a crucial role in fetal nervous system development. During the mid-first trimester, iodine requirements increased to support T4 hormone production [66]. Total T4, free T4, and T4 binding globulin levels are expected to rise, particularly after the seventh week of pregnancy, facilitating neuronal proliferation and migration in the cerebral cortex. During the second and third trimesters, serum TSH gradually increases, although it remains lower than in non-pregnant women [67].

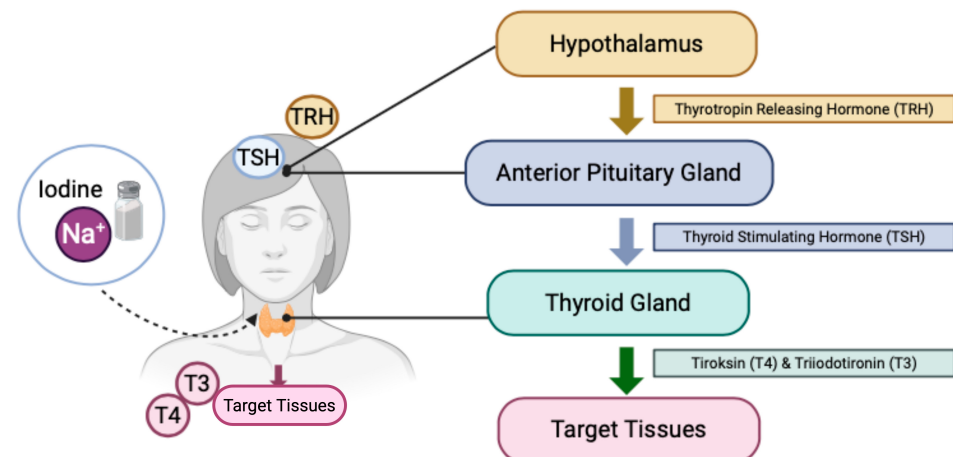


Figure 6. Mechanism of thyroid hormone synthesis. TSH—thyroid-stimulating hormone; TRH—thyrotropin-releasing hormone; T4—thyroxine; T3—triiodothyronine (Created in BioRender, <https://www.biorender.com/>, accessed on 30 December 2024).

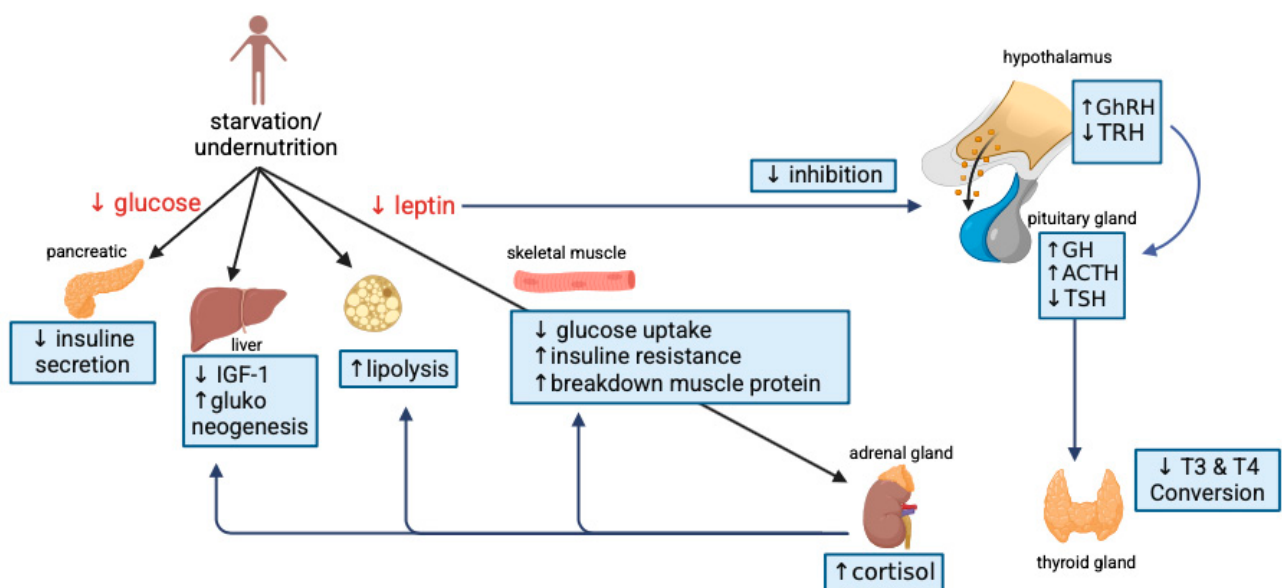


Figure 7. Endocrine dysregulation during starvation and undernutrition. IGF-1—insulin-like growth factor 1; GH—growth hormone; GhRH—growth hormone-releasing hormone; TSH—thyroid-stimulating hormone; TRH—thyrotropin-releasing hormone; ACTH—adrenocorticotrophic hormone; T4—thyroxine; T3—triiodothyronine; ↑—increase; ↓—decrease (Created in BioRender, <https://www.biorender.com/>, accessed on 18 January 2025).

3.4.2. Diabetes Mellitus

Children with low birth weight are often associated with an increased risk of obesity and type 2 diabetes in adulthood [68,69]. A Japanese study indicates that low birth weight markedly elevates the risk of type 2 diabetes relative to the control group, especially if

obesity or overweight occurs in adulthood [70]. Nutritional deficiencies during pregnancy and low birth weight result in the suboptimal development of insulin-producing cells in the pancreas, increasing susceptibility to metabolic disorders, including type 2 diabetes, later in life [71]. A study revealed that children with mild stunting had higher glucose and insulin levels, reduced beta-cell function, and increased insulin resistance as the main characteristics of type 2 diabetes [72]. Under conditions of nutritional deficiency, children experience a reduction in glucose levels, which leads to the decreased secretion of insulin and IGF-1 in the body. Decreased IGF-1 levels can trigger side effects in gluconeogenesis and increased cortisol levels. Additionally, reduced leptin levels can induce increased lipolysis and heightened insulin resistance, hindering glucose absorption in muscle tissues and increasing muscle protein breakdown, leading to elevated cortisol levels in the adrenal glands, as illustrated in Figure 7 [73,74].

3.4.3. Anemia

Anemia, or iron deficiency, is defined as a condition in which the hemoglobin (Hb) levels, relative to body height, are less than 11 g/dL in children under the age of five years. One in four children in Ethiopia experiences Coexisting Anemia and Stunting (CAS), with a prevalence rate of 24.4% from 2005 to 2016 [75]. Anemia in children typically occurs after six months of age and can worsen if iron-rich foods or supplements are not consumed adequately [76]. Fifty percent of anemia cases are attributed to iron deficiency; however, other causes, such as infections, environmental enteropathy, and the spread of infectious diseases, also contribute to the condition. Recurrent infections disrupt nutrient absorption in the digestive tract, leading to nutrient deficiencies and anemia in children [77,78]. Infections may also lead to inflammation, reducing IGF-1 levels, affecting nutrient intake, and increasing the excretion of essential nutrients for growth [9]. Malaria, for instance, induces inflammation and contributes to anemia [79]. Other potential causes of anemia include nutritional deficiencies, such as a lack of vitamins A, B6, B12, C, D, and E, riboflavin, copper, and folic acid. While these deficiencies are relatively rare, and their global contribution to anemia is likely minimal, the impact on anemia development can be synergistic in cases where dietary patterns result in micronutrient deficiencies [80]. Therefore, anemia is considered a multifactorial disease arising from iron deficiency, malaria, helminthiasis, schistosomiasis, hemoglobinopathies, and other micronutrient deficiencies. Additionally, anemia is closely associated with malnutrition-related diseases; conversely, conditions such as stunting, wasting, and obesity can contribute to the development of anemia [81].

4. Accelerated Strategies to Reduce Stunting Prevalence as Part of the Sustainable Development Goal (SDG) of Countries

The persistently high prevalence of stunting presents a significant barrier for several countries in achieving the Sustainable Development Goals (SDGs). According to the Conceptual Framework of the Determinants of Child Undernutrition, efforts to reduce stunting prevalence must target both direct and indirect causes of malnutrition. Direct causes are related to insufficient nutritional intake and recurrent infectious diseases. Indirect causes include social conditions (such as infant and child feeding practices, education, sanitation, and workplace conditions), food security (access to adequate nutrition), health environments (access to healthcare services), and household conditions (access to clean water, drinking water, and sanitation) [82,83]. Strategies implemented by various countries to prevent stunting encompass a range of interrelated interventions, including prevention strategies, intervention strategies, and multisectoral policies and approaches, as illustrated in Figure 8.

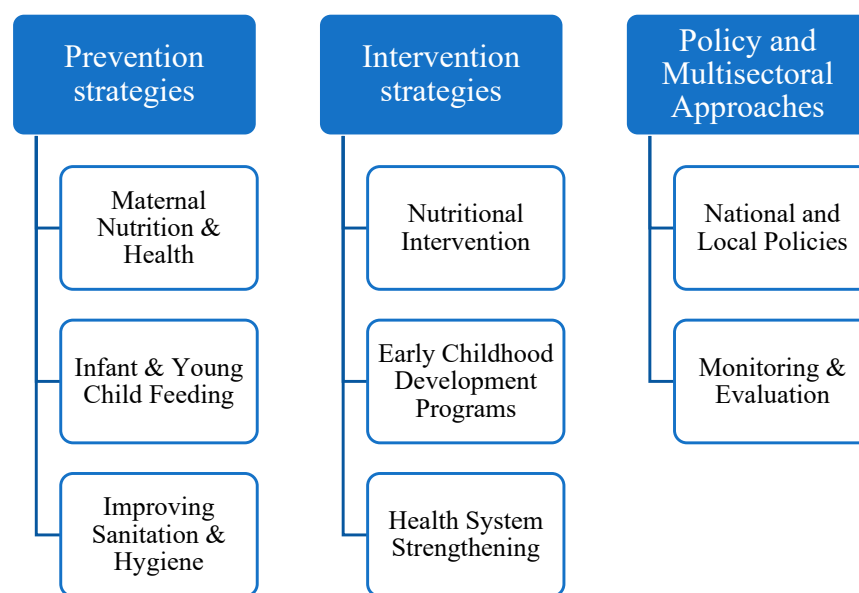


Figure 8. Multisectoral strategies for reducing stunting prevalence. (Created on Microsoft Word, <https://www.microsoft.com/en-us/microsoft-365/word>, accessed on 30 December 2024).

4.1. Prevention Strategies

Effective prevention strategies require addressing the root causes of stunting. Currently, national and international programs, including guidelines issued by the WHO, are available to adopt a comprehensive and multisectoral approach to preventing malnutrition. The WHO recommendations for achieving the Global Nutrition Targets 2025 include several interventions, such as providing energy and protein supplements to pregnant women, implementing programs that educate and promote nutritional needs during pregnancy, monitoring health quality, ensuring attention to hygienic conditions, clean water, and preventing infectious diseases [84].

4.1.1. Maternal Health and Nutrition

Maternal nutritional status during pregnancy is crucial for the child's early development. The Maternal Nutrition Literacy (MNL) program implemented for pregnant women in Indonesia has proven to have an impact on preventing stunting. During pregnancy, this literacy and education program includes education on exclusive breastfeeding, introducing complementary foods, practical demonstrations on preparing complementary foods, monitoring child growth, and promoting proper sanitation management [85]. The WHO has recommended routine antenatal care (ANC) for pregnant women and adolescent girls through platforms that promote health and prevent diseases. Among these recommendations is the consumption of micronutrients required for pregnant women and adolescent girls, including the use of calcium supplements (1.5–2 g daily) in populations with low calcium intake to prevent preeclampsia, daily iron (30–60 mg) and folic acid (0.4 mg) supplementation to prevent anemia in pregnant women, and vitamin A supplementation (10,000 IU daily or up to 25,000 IU weekly) in populations with a high prevalence of night blindness [86].

In addition, providing essential micronutrients during pregnancy is necessary to prevent stunting. Supplementation programs may include the provision of essential multiple micronutrients such as vitamin A, vitamin B12, zinc, iron, and iodine, as well as the enhancement of staple foods with key nutrients, such as flour, milk, sugar, and cereals, that may assist child growth and development. The consumption of iron–folic acid (IFA) supplements during pregnancy has been shown to significantly impact low birth weight, stunting,

and severe stunting in children under the age of 2 years in South Asia [87]. Micronutrient supplementation may also include the provision of lipid-based nutritional supplements (LNS) to provide essential fatty acids and proteins along with micronutrients in quantities of 20–50 grams per day [88,89].

4.1.2. Infant and Young Child Feeding

Infant and young child feeding practices are divided into two key phases: from 0 to 59 months, where exclusive breastfeeding (EBF) is recommended as it serves as protection and strengthens the infant's immune system; after 6 months, when infants are introduced to complementary foods that are appropriate and rich in essential nutrients, including vitamins and minerals. A study examining the impact of exclusive breastfeeding on children under 2 years old in eastern Indonesia found that children who received exclusive breastfeeding from wealthier households had a 50% lower likelihood of stunting compared to children who were not exclusively breastfed, particularly in poorer households. To strengthen complementary feeding practices, programs are needed to educate caregivers on introducing complementary foods, such as animal-source foods that are rich in nutrients and affordable within the household budget [90].

4.1.3. Improvement of Sanitation and Hygiene

Preventive behaviors to combat stunting through improved sanitation and clean water, as well as the promotion of hygiene practices such as handwashing with soap before meals, are essential in reducing the prevalence of stunting. Campaigns to promote handwashing can prevent diarrheal diseases and other infectious diseases among children [91,92].

4.2. Intervention Strategies

4.2.1. Nutritional Intervention

Programs using multivitamins and mineral supplements containing essential nutrients can enhance child growth and development. A study conducted in China revealed that the provision of a supplemental food containing protein, fats, carbohydrates, vitamins A, B1, B2, B12, and D3, folic acid, iron, zinc, and calcium, along with an educational program on complementary feeding, significantly improved the nutritional status of growth-stunted infants [93].

Through a quasi-experimental design, another study conducted in Afghanistan demonstrated the effectiveness of providing specific nutritious foods and implementing a Social and Behavior Change Communication (SBCC) program in preventing growth faltering during the first 1000 days of life for children under 2 years of age. In this program, pregnant and breastfeeding mothers received 7.5 kg of super cereal (250 g/day) during pregnancy and the first 6 months of breastfeeding, while children aged 6–23 months received lipid-based nutrient supplements (LNS), with 30 sachets (50 g/sachet/day) provided every month [94]. Additionally, another study reported that the provision of lipid-based nutrient supplements (LNS) and micronutrient powder (MNP) once daily to children aged 6–23 months in Pakistan led to a reduction in the prevalence of stunting among these children [95].

Specific nutritional interventions are crucial to addressing the consequences of stunting, such as impaired growth and development, dysbiosis or environmental enteric dysfunction (EED), hypothyroidism, and anemia. Specific nutritional strategies that can be implemented to mitigate these issues include the following:

Impaired Growth and Development

During periods of growth in children and adolescents, adequate nutrition can stimulate the combined action of growth hormone (GH) and insulin-like growth factor I (IGF-I) to

promote long-term growth. In promoting IGF-I activity, providing multiple micronutrients is more effective than single nutrient supplementation in stimulating linear growth. A study in Indonesia on stunted children (aged 48–60 months) with no other hereditary conditions found that supplementing multiple micronutrients, including vitamin A and zinc, significantly increased IGF-1 levels and Z-scores [96].

Gut Dysbiosis or Environmental Enteric Dysfunction (EED)

Efforts to address gut dysbiosis in the context of stunting can be approached through three key interventions: an application of probiotics, prebiotics, and synbiotics, as illustrated in Figure 9.

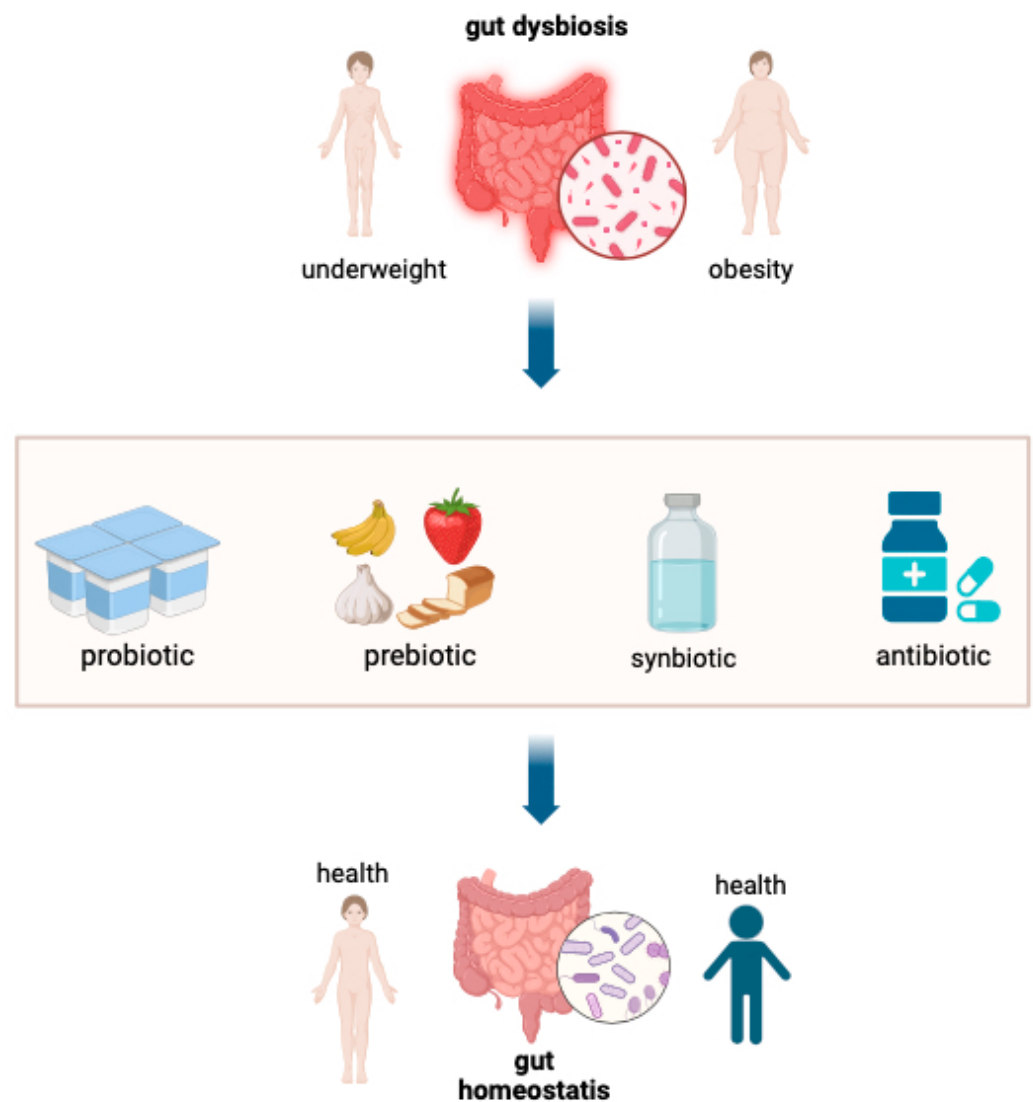


Figure 9. Scheme for treating gut dysbiosis in addressing stunting (Created in BioRender, <https://www.biorender.com/>, accessed on 24 December 2024).

Probiotics provide advantages to the host when administered in sufficient quantities. They can stimulate child growth by modulating the gut microbiota and immune system, inhibiting pathogen growth, preventing infections, and enhancing nutrient absorption. Meanwhile, prebiotics strengthen the growth of specific bacteria, particularly *bifidobacteria* and *lactobacilli*, which modulate short-chain fatty acid (SCFA) production to inhibit pathogen growth [97]. A study conducted by Barratt et al., 2022 in Bangladesh with infants aged 2–6 months receiving probiotics in the form of *B. infantis* EVC001 single-strain

or in combination with human milk oligosaccharide (LNnT) at a dose of 8 billion CFU per day showed significant increases in weight gain and a reduction in inflammation in the digestive tract [98]. Synbiotics, a combination of prebiotics and probiotics explicitly formulated to stimulate the effects of probiotic organisms, have also shown benefits. For instance, administering synbiotics (*B. infantis* EVC001 combined with lacto-N-neotetraose [LNnT]) led to increased weight compared to a placebo group [99]. Children with a history of exclusive breastfeeding have more *Bifidobacterium* and *Odoribacter splanchnicus* bacteria than those not exclusively breastfed [92]. In addition to preventing and managing diarrhea in children, improving immunization coverage can offer better protection. To improve and maintain a balanced gut microbiota composition, children should consume healthy fermented foods and a proportionate intake of fiber, fats, carbohydrates, and proteins [16].

Hypothyroidism

Adequate iodine intake is necessary to maintain normal thyroid function. The WHO recommends iodine intake levels for infants and children to be 90–120 µg/L daily. Breast milk is a key source of iodine for infants in the first six months of life. However, the mother's dietary iodine intake directly influences the iodine content. Therefore, ensuring adequate iodine nutrition in pregnant and lactating women is critical not only for the mother's health but also for the growth and development of the infant [100]. In addition to iodine, other nutrients such as iron, vitamin D, zinc, and other micronutrients also play a role in thyroid function. Iron deficiency, for instance, can reduce thyroid peroxidase activity, an enzyme essential for thyroid hormone production. Thus, integrated nutrition interventions that address multiple micronutrient deficiencies are more effective in preventing thyroid-related growth delays [101]. A study conducted in China revealed that the provision of a supplementary food product (hibao) containing protein, fat, carbohydrates, vitamins A, B1, B2, B12, D3, folic acid, iron, zinc, and calcium, combined with an educational program on complementary feeding practices, significantly improved the nutritional status of infants experiencing growth faltering [93].

Anemia

Currently, both national and international programs are available, including guidelines issued by the WHO to adopt a comprehensive and multisectoral approach to malnutrition prevention. Micronutrient supplementation has been shown to significantly reduce the prevalence of anemia, especially in vulnerable groups such as pregnant women, infants, and young children, thereby contributing to improved health outcomes and nutritional status [84]. A study conducted in Pakistan in 2023 demonstrated that the provision of Wawamum LNS-MQ (lipid-based nutrient supplement—medium quantity) could increase hemoglobin concentration, micronutrient status, and other growth parameters in children aged 6 to 23 months. This intervention can be enhanced as a form of malnutrition prevention in Pakistan and other developing countries [102]. Another evidence comes from the administration of Yingnyangbao, which contains energy, protein, vitamins A, D, B1, B2, B12, folic acid, calcium, iron, and zinc, has been shown to effectively increase hemoglobin concentration, reduce the risk of anemia, and improve nutritional status, thereby lowering the prevalence of stunting [101]. Stewart et al. (2020) conducted a Multiarm Cluster-Randomized Controlled Trial involving 125 communities, which revealed that the group of children aged 6 to 18 months and pregnant women through children aged 6 months who received lipid-based nutrient supplements exhibited a 25% lower prevalence of anemia and iron deficiency compared to the control group [103].

4.2.2. Early Childhood Development Programs

These programs include education and family support to stimulate early cognitive and physical development, which can help mitigate the consequences of stunting. Early childhood development programs must also be supported by various initiatives that educate and promote the nutritional needs of pregnant women, nutrition assessments, immunization campaigns, monitoring of child growth, ensuring proper hygiene, providing access to clean water, and preventing infectious disease [84]. Moreover, the family component of ECD programs complements health efforts by promoting a nurturing and stimulating home environment essential for healthy child development. This support may come in the form of parenting education, nutritional guidance, and access to social services that ensure families have the resources to provide adequate care [104].

4.2.3. Strengthening the Health System

Strengthening the health system aims to provide optimal and comprehensive health-care services for mothers and children, including regular check-ups, immunization, and growth monitoring. The WHO has explained the six building blocks of a health systems, which are the following: (1) health services that are effective, safe, and efficient [105]; (2) health workforce that are sufficient, well-distributed, skilled, and responsive; (3) health information systems that produce and use reliable data for decision making; (4) access to essential medicines and technologies that are of high quality, safe, and cost-effective; (5) health financing systems that ensure equitable access; (6) leadership and governance that provide strong policy frameworks, oversight, and accountability. As part of Indonesia's national strategy to accelerate the prevention of child stunting, several programs have been introduced to improve access to and the quality of nutrition and healthcare services. These include the provision of access to the National Health Insurance (JKN), access to family planning (FP) services, and conditional cash transfer programs for low-income families, such as the Family Hope Program (PKH) [82].

4.3. Multisectoral Policies and Approaches

Stunting is a complex issue that requires coordinated solutions across multiple sectors. Effective policies that can be implemented include:

4.3.1. Local and National Policies

Support from local and national policies is crucial, integrating nutrition into broader policies across education, agriculture, health, and social protection sectors. Several integrated interventions have been implemented, such as the WASH (Water, Sanitation, Hygiene) program in Bangladesh and Kenya, the SHINE (Sanitation, Hygiene, Infant Nutrition Efficacy) trial program in Zimbabwe, and the STRANAS (National Strategy to Accelerate Stunting Reduction) program in Indonesia. Multisectoral policy interventions have a significant impact on reducing the prevalence of stunting worldwide [82,90].

4.3.2. Monitoring and Evaluation

Monitoring and evaluation focus on assessing the results achieved, including the program's impact and outcomes, identifying any discrepancies during implementation and monitoring factors that can accelerate the prevention of stunting [82].

5. Limitations and Future Research

There are some limitations to our narrative review. In this study, only four databases and Mendeley were used as access to find the sources of the articles being reviewed. A considerable proportion of the reviewed literature, particularly that from the Asian region,

predominantly comprised studies conducted in Indonesia. To gain a more comprehensive understanding of the factors and conditions linked to stunting, it would be beneficial to include more research from a broader range of countries, especially in countries with a high prevalence of stunting.

As authors, we made every effort to ensure that the studies we collected were as objective as possible, as may be indicated by, among other things, the large number of studies cited and the reporting of all study results. However, despite the authors' efforts, a narrative review is a form of scientific work that may carry a greater risk of subjective evaluation than other review works, such as a systematic review or meta-analysis.

In future studies, there is a need for long-term monitoring of both prevention and intervention programs. Longitudinal studies and implementation research across different policy and health system contexts will be particularly valuable in informing sustainable, evidence-based strategies to meet global nutrition targets, including the SDGs.

6. Conclusions

This review has explored the significant global burden of stunting and its short- and long-term consequences, including impaired physical growth, cognitive delays, dysbiosis, endocrine dysfunction, and anemia. The evidence suggests that early interventions, particularly those targeting maternal nutrition and child health in the first 1000 days of life, are critical to preventing permanent growth failure and developmental setbacks. This also raises attention to which strategies that may accelerate the reduction of stunting incidence by strengthening three following aspects: (1) Prevention Strategies, including maternal health and nutrition, promotion of exclusive breastfeeding and appropriate complementary feeding, as well as improved sanitation and hygiene practices; (2) Intervention Strategies, such as micronutrient supplementation, early childhood development programs, and the strengthening of healthcare systems to ensure continuity and quality of care for mothers and children; (3) Multisectoral Policies and Approaches emphasizing the integration of nutrition into broader policy frameworks at both local and national levels, and the importance of robust monitoring and evaluation systems. Looking forward, further research and action are needed in several key areas: (1) Future programs should be adapted to local sociocultural and economic realities, especially in high-burden regions, through participatory approaches involving community members and local stakeholders; (2) more longitudinal research is needed to evaluate the lasting effects of stunting interventions, particularly those targeting early development and maternal care; (3) governments and international partners must sustain political will, policy alignment, and funding to support multisectoral strategies that aim not only to treat but to prevent stunting at its roots.

Author Contributions: Conceptualization, A.Y.C. and M.A.K.; writing—original draft preparation, A.T.M.; writing—review and editing, A.T.M., A.K., A.Y.C. and M.A.K.; visualization, A.T.M.; supervision, A.Y.C., A.K. and M.A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Padjadjaran University Post Graduate Study Scholarship year 2024–2025.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Tabulation of impacts and the causes of stunting.

Number	Respondent Characteristics	Research Objectives	Main Findings	Ref.
3.1. Growth Failure				
1	185 children aged 6 to 59 months	To determine the prevalence of putative developmental delay and the variables linked to it in children under five in rural Pakistan suffering from severe acute malnutrition (SAM) without comorbidities.	Suspected global developmental delay is much more common in children with severe acute malnutrition, particularly in those who were not nursed exclusively and had a history of contact with TB-positive adults.	[39]
2	78 children aged 5 to 12 months	To explore the correlation between linear growth, systemic inflammation, and gut damage in infants at risk of stunting.	Stunted children show differences in their fecal microbiota compared to non-stunted children, which are associated with increased systemic inflammatory markers.	[52]
3	710 children aged 4 to 6 years	To evaluate the association between linear growth and hemoglobin concentrations during growth with motor, cognitive, and socio-emotional development in Ghana.	Birth length-for-age z-score (LAZ) is significantly associated with cognitive development and hemoglobin levels at 18 months; however, no significant correlation was found with motor or socio-emotional development.	[106]
3.2. Impaired Cognition				
1	51 children aged 1 month to 3 years	To assess cognitive development in children experiencing stunting and malnutrition compared to their well-nourished peers.	The tendency for cognitive, motor, and adaptive skills is significantly lower in stunted children compared to those with malnutrition and those with normal development.	[40]
2	300 children aged 1 to 3 years	To investigate the cognitive development of stunted children and malnutrition compared to children with normal nutrition.	Children experiencing stunting are at a higher risk of cognitive developmental delays compared to children who are not stunted.	[107]
3	4379 children aged 0 to 5 years	To analyze the correlation between stunted children and its impact on educational outcomes and cognitive performance in adulthood in Indonesia	Stunted children and those of relatively small stature are significantly associated with cognitive development, leading to poorer educational outcomes.	[45]

Table A1. Cont.

Number	Respondent Characteristics	Research Objectives	Main Findings	Ref.
3.3. Dysbiosis (Infection, Enteric Rectical Dysfunction)				
1	224 children aged 24 to 59 months	To investigate the relationship between stunting, sanitation, intestinal infections, and environmental enteric dysfunction (EED) in Ethiopia.	Stunted children are significantly associated with hygiene, poor dietary patterns, inadequate sanitation, intestinal infections, and environmental enteric dysfunction (EED).	[108]
2	42 children aged 24 to 59 months	To determine the association between intestinal infections, growth biomarkers (IGF-1), and gut microbiota composition in children with stunting in Indonesia	The gut microbiota profile of stunted children exhibits dysbiosis, characterized by an overabundance of taxa that induces inflammation, metabolic abnormalities, and unhealthy dietary patterns.	[16]
3	82 children aged 6 to 59 months	To examine the relationship between intestinal inflammation and stunted children under 5 years old in Ethiopia.	A strong correlation exists between stunting and gastrointestinal inflammation, diarrhea, breastfeeding duration, environmental factors, and family size.	[109]
4	131 children aged 3 to 5 years	To investigate alterations in gut microbiota composition between stunted children and those with normal nutritional status.	Prevotella 9 levels are significantly lower in stunted children, indicating lower fiber intake, which is supported by nutritional intake data compared to normal children.	[53]
5	42 children aged 2 to 5 years	To investigate the gut microbiota composition and related variables that affect stunted and non-stunted children in Jakarta's slums.	Stunted children exhibit a gut microbiota composition significantly different from non-stunted children. This composition is characterized by an increased prevalence of pathogenic bacteria and a reduced abundance of beneficial bacteria.	[99]
3.4. Metabolic System Disorder				
1	3046 school-aged children, 8 to 10 years old	To examine the prevalence of stunting and how iodine deficiency disorders (IDDs) might predict stunting in Aseer region primary school students.	IDDs may predict stunting, with students exhibiting clinical goiter and those with urinary iodine concentration (UIC) levels < 17 µg/L showing a significant association with stunting.	[63]

Table A1. Cont.

Number	Respondent Characteristics	Research Objectives	Main Findings	Ref.
2	1135 adults aged 30 to 89 years	To examine the correlation between birth weight and type 2 diabetes mellitus in the general population of Japan.	Low birth weight in the Japanese population is associated with an increased risk of acquiring type 2 diabetes mellitus, particularly among those who are overweight or obese.	[70]
3	1682 adults aged 18 to 68 years	To explore the relationship between low stature and increased sitting height ratio (SHR) as indications of stunting and obesity in adults.	Short stature is identified as a risk factor for obesity in both adult men and women in Portugal.	[110]
4	3534 adult men and women aged 30 years and above	Testing the association between childhood stunting and a higher risk of cardiometabolic disorders in adulthood.	Adults who experienced stunting during childhood tend to have less muscle mass and subcutaneous fat and may exhibit a higher tendency for visceral fat accumulation.	[111]
5	3844 children and adolescents aged 7 to 18 years	To investigate the correlation between short stature, obesity, and cardiometabolic risk factors in children and adolescents in Iran.	Children and adolescents with short height are at an elevated risk of acquiring metabolic syndrome, abdominal obesity, and hypertension relative to their counterparts of normal size.	[81]
3.5. Anemia				
1	21,172 children aged 6–59 months	Investigating the prevalence of anemia and stunting and identifying the factors influencing these conditions in children aged 6–59 months in Ethiopia.	The prevalence of anemia and stunting is 24.4%, with a 95% Confidence Interval (CI) of (23.8–24.9%). Key risk factors contributing to this prevalence include the following: anemia in mothers, very short stature of mothers, low maternal education, poor hygiene practices, and living in rural areas.	[75]
2	750 children aged 12–59 months	Assessing the status of micronutrients and the correlation with hemoglobin levels in children aged 12–59 months with stunting.	Two out of three children with stunting also experience anemia. Malaria and other infections, in addition to micronutrient deficiencies, significantly contribute to anemia in these children.	[112]
3	21,918 children aged 6–59 months	Examining the relationship between malnutrition (stunting, wasting, underweight) and open defecation and how these relate to anemia in children aged 6–59 months in Ethiopia.	In Ethiopia, childhood malnutrition partially mediates the relationship between open defecation and anemia, highlighting the importance of sanitation in addressing both issues.	[76]

Table A1. Cont.

Number	Respondent Characteristics	Research Objectives	Main Findings	Ref.
Environment, Social, and Economy				
1	750 children aged 1–5 years	Evaluating the socioeconomic factors, household conditions, anthropometric values, and clinical changes based on early childhood development (ECD) outcomes for stunted children aged 1–5 years.	Stunting is closely related to developmental outcomes. Children with severe stunting tend to have lower early childhood development (ECD) scores, and this gap persists or even worsens over time.	[113]

Appendix B

Table A2. Tabulation of strategies both intervention and prevention studies.

No.	Respondent Characteristics	Intervention	Main Findings	Ref
A. Prevention Strategies				
1	85 mothers with children aged 0–6 months	Education and simulation classes (principles of breastfeeding, introduction to complementary feeding), monthly home visits totalling 15 visits, growth monitoring, and sanitation monitoring.	Maternal nutritional literacy (MNL) plays a crucial role in the prevention of stunting, with a focus not only on stunted children but also on healthy children. Emphasizing exclusive breastfeeding for stunted children is central to MNL efforts.	[85]
2	3120 mothers with children aged 0–5 months	Specific nutrition intervention programs will be implemented over 36 months, divided into 4 phases with gradual evaluations. These programs will include monitoring of development and cooking practices or demonstrations.	The Suchana program has demonstrated positive outcomes in promoting exclusive breastfeeding practices among children in Bangladesh, with exclusive breastfeeding being identified as a key factor in reducing stunting.	[114]
3	408 children aged 6–24 months	The data collection consists of a quantitative survey examining breastfeeding practices, demographic and socioeconomic characteristics, and monthly family expenditures. The survey utilizes a structured questionnaire conducted by professional interviewers.	Exclusive breastfeeding can reduce the likelihood of children experiencing stunting. It provides a cost-effective and efficient solution for low-income households to address stunting.	[115]

Table A2. Cont.

No.	Respondent Characteristics	Intervention	Main Findings	Ref
4	8451 caregivers with children aged 6–23 months	Supplementary feeding provision (including protein, fat, carbohydrates, vitamin A, B1, B2, B12, D3, folic acid, iron, zinc, and calcium) and complementary feeding counseling for caregivers.	Community-based complementary food supplements and dietary guidance can enhance feeding patterns and reduce the incidence of anemia.	[92]
B. Intervention Strategies				
1	2928 and 3205 households with children under 2 years of age	Pregnant and breastfeeding women received Super Cereal 7.5 kg (250 g/day) during pregnancy and for six months of breastfeeding. Children aged 6–23 months were given 30 sachets of lipid-based nutritional supplements (50 g/sachet/day) each month.	The use of small-quantity nutrient supplements (SQNS) alongside social and behavioral change communication (SBCC) during the first 1000 days of life is linked to a decrease in stunting and malnutrition and improvements in infant and young child feeding practices for children under 2 years old.	[93]
2	6674 children under 5 years of age	Female healthcare workers distributed a soy–wheat blend to pregnant and breastfeeding women, as well as micronutrient powder to children aged 6–23 months and 24–59 months.	Short-term nutritional absorption through the Wawamum intervention is not effective in reducing stunting. Proven communication about behavior change must be supported to enhance complementary feeding behaviors.	[116]
3	110 children aged 6–23 months	Daily consumption of Wawamum, consisting of one sachet of 50 g, was given to children over 12 months.	Wawamum (LNS-MQ) has proven its efficacy in enhancing micronutrient status, hemoglobin levels, and growth metrics in children aged 6 to 23 months.	[102]
4	4011 women in early pregnancy (under 20 weeks) and 1552 adolescents	- Mothers and children received small-quantity lipid-based nutrient supplements (SQ-LNS). - Mothers received iron–folic acid (IFA), and children received lipid-based nutrients (LNS). - Mothers received IFA, and children received micronutrient powder (MNP). The duration of supplementation for pregnant mothers is until the child reaches 6 months, while for children, supplementation continues until they are 24 months old.	Providing LNS before birth may reduce newborn stunting and low birth weight, significantly reducing wasting compared to IFA supplementation.	[88]

Table A2. Cont.

No.	Respondent Characteristics	Intervention	Main Findings	Ref
5	971 children aged 6–72 months	‘Chispuditos®’, a hot beverage enriched with micronutrients (atole + MN), providing 9 mg of zinc and 12.5 mg of iron, or lactose-free milk, was provided for 18 months.	Long-term micronutrient supplementation in beverages does not significantly impact growth or nutritional status.	[117]
6	1059 children aged 15 months to 7 years,	Food supplements (NEWSUP), which contain plants rich in polyphenols and omega-3 fatty acids, along with various micronutrients and high-protein content, or fortified blended foods (FBFs) or traditional rice-based breakfast as a control food, were administered every morning for 23 weeks.	NEWSUP has been shown to improve working memory and reduce BMI compared to the normal group. Additionally, NEWSUP increases hemoglobin concentration in children with anemia. Supplementation over 23 weeks enhances executive function, brain health, and nutritional status in children.	[118]
7	67 children aged 2 to 6 months,	Severely malnourished infants were provided with probiotics (<i>Bifidobacterium infantis</i> EVC001) or synbiotics (<i>B. infantis</i> EVC001 + Lacto-N-neotetraose [LNnT]) or a placebo (lactose) for four weeks, followed by a four-week follow-up after supplementation.	Severely malnourished infants exhibit higher weight gain when given probiotics.	[99]
8	151 children aged 3 to 24 months	The intervention involving the commercial strain of <i>B. infantis</i> from a U.S. donor (EVC001) was administered daily for 28 days to the control group with or without human milk oligosaccharides (HMOs), lacto-N-neotetraose, or the placebo SYNERGIE.	The abundance of <i>Bifidobacterium infantis</i> increased in the feces of infants with severe acute malnutrition (SAM). However, the increase was 10 to 100 times lower than the abundance observed in healthy controls.	[98]
9	304 children aged 29 to 49 months	Preschool children were given a dual-micronutrient powder or placebo fortification in their food six days per week (excluding Sundays and public holidays) for 8 months.	Providing micronutrients during the first 1000 days of life can reduce developmental delays and decrease anemia and iron deficiency.	[119]
10	387 mothers with children under 2 years of age.	The intensive nutrition counseling intervention, including information on maternal nutrition, exclusive breastfeeding, and complementary feeding demonstration, was provided along with LNS for children aged 6 to 18 months as well as pregnant or breastfeeding women until the infant reached 6 months.	Children who received intensive nutrition counseling and lipid-based nutrient supplementation (LNS) for pregnant women until the child reached 18 months of age had a lower prevalence of anemia and iron-deficiency anemia than children in the control group.	[103]

Table A2. Cont.

No.	Respondent Characteristics	Intervention	Main Findings	Ref
11	5920 preschool children aged 3 to 6 years	The questionnaire filled out by the child's caregiver encompassed demographic attributes of the child, including age, gender, ethnicity, source of drinking water, geographic location, degree of urbanization, and exposure to secondhand smoking.	Iodine nutrition in preschool children and their physical growth is linked to the child's age and height.	[120]
12	834 mothers with children aged 6 to 59 months	Health educators conducted a behavioral intervention on iodine intake through food over 17 months. The program included education to increase the utilization of iodized salt, reduce the prevalence of iodine deficiency, and improve children's linear growth.	The prevalence of stunting among children in the intervention group at the start of the study (40.5%) decreased by the end of the study (15.1%). Additionally, urinary iodine concentrations in the intervention group increased compared to the normal group.	[121]
13	96,512 mothers with children under 2 years of age.	The study utilized a nationally representative survey on socio-demographic, health, and nutrition indicators. Exposure to antenatal iron–folic acid (IFA) supplementation was gathered retrospectively through maternal recall.	Antenatal iron–folic acid (IFA) supplementation was significantly linked to a reduced risk of below-average birth size, stunting, and severe stunting in children under 2 years of age in South Asia.	[87]
C. Policy and Multisectoral Approaches				
1	253 preschool children aged 3 to 5 years,	The 12-month health education program included education on nutrition deficiencies, demonstrations, and explanations on preparing nutritious meals and various healthy recipes that provide protein, energy, calcium, and iron to mothers.	Children who received the intervention showed improved cognitive development compared to the control group. Home-based, nutrition-focused foods contributed to this enhancement.	[122]
2	2222 mothers with children aged 6 to 24 months.	Community health volunteers conducted 16 nutrition education and stimulation sessions (every two weeks) under a program named Msingi Bora. The Msingi Bora curriculum emphasized five key practices: responsive play, responsive communication, hygiene, nutrition, and fostering love and respect within the family.	Parenting interventions conducted by trained community health volunteers in the mother–child group effectively improved child development within the community.	[123]

References

- de Onis, M.; Branca, F. Childhood stunting: A global perspective. *Matern. Child Nutr.* **2016**, *16*, 16–26. [CrossRef] [PubMed]
- WHO. *WHO Child Growth Standards: Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development*; World Health Organization: Geneva, Switzerland, 2006.
- Soliman, A.; De Sanctis, V.; Alaraj, N.; Ahmed, S.; Alyafei, F.; Hamed, N.; Soliman, N. Early and long-term consequences of nutritional stunting: From childhood to adulthood. *Acta Biomed.* **2021**, *92*, e2021168. [CrossRef]
- Fleming, T.P.; Watkins, A.J.; Velazquez, M.A.; Mathers, J.C.; Prentice, A.M.; Stephenson, J.; Barker, M.; Saffery, R.; Yajnik, C.S.; Eckert, J.J.; et al. Origins of lifetime health around the time of conception: Causes and consequences. *Lancet* **2018**, *391*, 1842–1852. [CrossRef] [PubMed]
- Stephenson, J.; Heslehurst, N.; Hall, J.; Schoenaker, D.A.J.M.; Hutchinson, J.; Cade, J.E.; Poston, L.; Barrett, G.; Crozier, S.R.; Barker, M.; et al. Before the beginning: Nutrition and lifestyle in the preconception period and its importance for future health. *Lancet* **2018**, *391*, 1830–1841. [CrossRef]
- van Zyl, C.; van Wyk, C. Exploring factors that could potentially have affected the first 1000 days of absent learners in South Africa: A qualitative study. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2768. [CrossRef]
- Victora, C.G.; de Onis, M.; Shrimpton, R. Linear growth faltering should be assessed in absolute and relative terms. *J. Nutr.* **2014**, *144*, 2092–2093. [CrossRef] [PubMed]
- WHO. Stunting in a Nutshell. 2015. Available online: <https://www.who.int/news/item/19-11-2015-stunting-in-a-nutshell> (accessed on 16 January 2025).
- Millward, D.J. Nutrition, infection and stunting: The roles of deficiencies of individual nutrients and foods, and of inflammation, as determinants of reduced linear growth of children. *Nutr. Res. Rev.* **2017**, *30*, 50–72. [CrossRef]
- WHO. Global Nutrition Targets 2025: Stunting Policy Brief. Available online: <https://iris.who.int/handle/10665/149019> (accessed on 16 January 2025).
- Hörnell, A.; Lagström, H. Infant feeding—A scoping review for Nordic Nutrition Recommendations 2023. *Food Nutr. Res.* **2024**, *68*, 10-29219. [CrossRef]
- Irarrázaval, B.; Barja, S.; Bustos, E.; Doirsaint, R.; Senethmm, G.; Guzmán, M.P.; Uauy, R. Influence of feeding practices on malnutrition in haitian infants and young children. *Nutrients* **2018**, *10*, 382. [CrossRef]
- UNICEF. Improving Young Children’s Diets during the Complementary Feeding Period. In *UNICEF Programming Guidance*; UNICEF: New York, NY, USA, 2020.
- Titaley, C.R.; Ariawan, I.; Hapsari, D.; Muasyaroh, A.; Dibley, M.J. Determinants of the stunting of children under two years old in Indonesia: A multilevel analysis of the 2013 Indonesia basic health survey. *Nutrients* **2019**, *11*, 1106. [CrossRef]
- Budge, S.; Parker, A.H.; Hutchings, P.T.; Garbutt, C. Environmental enteric dysfunction and child stunting. *Nutr. Rev.* **2019**, *77*, 240–253. [CrossRef]
- Rinanda, T.; Riani, C.; Artarini, A.; Sasongko, L. Correlation between gut microbiota composition, enteric infections and linear growth impairment: A case–control study in childhood stunting in Pidie, Aceh, Indonesia. *Gut Pathog.* **2023**, *15*, 54. [CrossRef] [PubMed]
- Vonaesch, P.; Randeramanana, R.; Gody, J.-C.; Collard, J.-M.; Giles-Vernick, T.; Doria, M.; Vigan-Womas, I.; Rubbo, P.-A.; Etienne, A.; Andriatahirintsoa, E.J.; et al. Identifying the etiology and pathophysiology underlying stunting and environmental enteropathy: Study protocol of the AFRIBIOTA project. *BMC Pediatr.* **2018**, *18*, 236. [CrossRef]
- Dewey, K.G.; Begum, K. Long-term consequences of stunting in early life. *Matern. Child Nutr.* **2011**, *7* (Suppl. 3), 5–18. [CrossRef]
- UNICEF; WHO; World Bank Group. United Nations Children’s Fund (UNICEF), World Health Organization (WHO), International Bank for Reconstruction and Development/The World Bank. In *Levels and Trends in Child Malnutrition: UNICEF/WHO/World Bank Group Joint Child Malnutrition Estimates: Key Findings of the 2023 Edition*; UNICEF: New York, NY, USA; WHO: Geneva, Switzerland, 2023.
- Kim, K.; Melough, M.; Kim, D.W.; Sakaki, J.; Lee, J.; Choi, K.; Chun, O. Nutritional adequacy and diet quality are associated with standardized height-for-age among U.S. children. *Nutrients* **2021**, *13*, 1689. [CrossRef] [PubMed]
- Shi, H.; Ren, Y.; Jia, Y. Effects of nutritional interventions on the physical development of preschool children: A systematic review and meta-analysis. *Transl. Pediatr.* **2023**, *12*, 991–1003. [CrossRef]
- Chiplonkar, S.; Kajale, N.A.; Sanwalka, N. A Review of Food-Based Intervention Strategies for Improving Micronutrient Status and Health During Childhood. *Curr. Res. Nutr. Food Sci.* **2022**, *10*, 407–426. [CrossRef]
- Allen, L.H.; Pearson, J.M.; Olney, D.K. Provision of multiple rather than two or fewer micronutrients more effectively improves growth and other outcomes in micronutrient-deficient children and adults. *J. Nutr.* **2009**, *139*, 1022–1030. [CrossRef]
- Inzaghi, E.; Pampanini, V.; Deodati, A.; Cianfarani, S. The Effects of Nutrition on Linear Growth. *Nutrients* **2022**, *14*, 1752. [CrossRef] [PubMed]
- Kazemi, A.; Speakman, J.R.; Soltani, S.; Djafarian, K. Effect of calorie restriction or protein intake on circulating levels of insulin like growth factor I in humans: A systematic review and meta-analysis. *Clin. Nutr.* **2020**, *39*, 1705–1716. [CrossRef]

26. Levine, M.E.; Suarez, J.A.; Brandhorst, S.; Balasubramanian, P.; Cheng, C.-W.; Madia, F.; Fontana, L.; Mirisola, M.G.; Guevara-Aguirre, J.; Wan, J.; et al. Low protein intake is associated with a major reduction in IGF-1, cancer, and overall mortality in the 65 and younger but not older population. *Cell Metab.* **2014**, *19*, 407–417. [[CrossRef](#)]
27. Fazeli, P.K.; Klibanski, A. Determinants of GH resistance in malnutrition. *J. Endocrinol.* **2014**, *220*, R57–R65. [[CrossRef](#)] [[PubMed](#)]
28. Ahmad, S.S.; Ahmad, K.; Lee, E.J.; Lee, Y.H.; Choi, I. Implications of Insulin-Like Growth Factor-1 in Skeletal Muscle and Various Diseases. *Cells* **2020**, *9*, 1773. [[CrossRef](#)]
29. Yoshida, T.; Delafontaine, P. Mechanisms of IGF-1-Mediated Regulation of Skeletal Muscle Hypertrophy and Atrophy. *Cells* **2020**, *9*, 1970. [[CrossRef](#)]
30. Bikle, D.D.; Tahimic, C.; Chang, W.; Wang, Y.; Philippou, A.; Barton, E.R. Role of IGF-I signaling in muscle bone interactions. *Bone* **2015**, *80*, 79–88. [[CrossRef](#)] [[PubMed](#)]
31. Inagaki, T.; Lin, V.Y.; Goetz, R.; Mohammadi, M.; Mangelsdorf, D.J.; Kliewer, S.A. Inhibition of Growth Hormone Signaling by the Fasting-Induced Hormone FGF21. *Cell Metab.* **2008**, *8*, 77–83. [[CrossRef](#)]
32. Laeger, T.; Henagan, T.M.; Albarado, D.C.; Redman, L.M.; Bray, G.A.; Noland, R.C.; Münzberg, H.; Hutson, S.M.; Gettys, T.W.; Schwartz, M.W.; et al. FGF21 is an endocrine signal of protein restriction. *J. Clin. Investig.* **2014**, *124*, 3913–3922. [[CrossRef](#)]
33. LeRoith, D.; Yakar, S. Mechanisms of Disease: Metabolic effects of growth hormone and insulin-like growth factor 1. *Nat. Clin. Pract. Endocrinol. Metab.* **2007**, *3*, 302–310. [[CrossRef](#)]
34. Moøller, N.; Joørgensen, J.O.L. Effects of growth hormone on glucose, lipid, and protein metabolism in human subjects. *Endocr. Rev.* **2009**, *30*, 152–177. [[CrossRef](#)]
35. Oscarsson, J.; Johannsson, G.; Johannsson, J.; Lundberg, P.; Lindstedt, G.; Bengtsson, B. Diurnal variation in serum insulin-like growth factor (IGF)-I and IGF binding protein-3 concentrations during daily subcutaneous injections of recombinant human growth hormone in GH-deficient adults. *Clin. Endocrinol.* **1997**, *46*, 63–68. [[CrossRef](#)]
36. Alam, A.; Richard, S.A.; Fahim, S.M.; Mahfuz, M.; Nahar, B.; Das, S.; Shrestha, B.; Koshy, B.; Mduma, E.; Seidman, J.C.; et al. Impact of early-onset persistent stunting on cognitive development at 5 years of age: Results from a multi-country cohort study. *PLoS ONE* **2020**, *15*, e0227839. [[CrossRef](#)]
37. Woldehanna, T.; Behrman, J.R.; Araya, M.W. The Effect of Early Childhood Stunting on Children’s Cognitive Achievements: Evidence from Young Lives Ethiopia. 2017. Available online: www.younglives.org.uk (accessed on 24 December 2024).
38. Saleem, J.; Zakar, R.; Zakar, M.Z.; Belay, M.; Rowe, M.; Timms, P.M.; Scragg, R.; Martineau, A.R. High-dose Vitamin D 3 in the treatment of severe acute malnutrition: A multicenter double-blind randomized controlled trial. *Am. J. Clin. Nutr.* **2018**, *107*, 725–733. [[CrossRef](#)] [[PubMed](#)]
39. Saleem, J.; Zakar, R.; Bukhari, G.M.J.; Fatima, A.; Fischer, F. Developmental delay and its predictors among children under five years of age with uncomplicated severe acute malnutrition: A cross-sectional study in rural Pakistan. *BMC Public Health* **2021**, *21*, 1397. [[CrossRef](#)] [[PubMed](#)]
40. Handryastuti, S.; Pusponegoro, H.D.; Nurdadi, S.; Chandra, A.; Pramita, F.A.; Soebadi, A.; Widjaja, I.R.; Rafli, A. Comparison of Cognitive Function in Children with Stunting and Children with Undernutrition with Normal Stature. *J. Nutr. Metab.* **2022**, *2022*, 75727. [[CrossRef](#)]
41. Jáuregui-Lobera, I. Iron deficiency and cognitive functions. *Neuropsychiatr. Dis. Treat.* **2014**, *10*, 2087–2095. [[CrossRef](#)]
42. Benton, D. Micronutrient status, cognition and behavioral problems in childhood. *Eur. J. Nutr.* **2008**, *47*, 38–50. [[CrossRef](#)]
43. Semba, R.D.; Trehan, I.; Gonzalez-Freire, M. Perspective: The potential role of essential amino acids and the mechanistic target of rapamycin complex 1 (mTORC1) pathway in the pathogenesis of child stunting. *Adv. Nutr.* **2016**, *7*, 853–865. [[CrossRef](#)]
44. Sancak, Y.; Bar-Peled, L.; Zoncu, R.; Markhard, A.L.; Nada, S.; Sabatini, D.M. Ragulator-rag complex targets mTORC1 to the lysosomal surface and is necessary for its activation by amino acids. *Cell* **2010**, *141*, 290–303. [[CrossRef](#)]
45. Lestari, E.; Siregar, A.; Hidayat, A.K.; Yusuf, A.A. Stunting and its association with education and cognitive outcomes in adulthood: A longitudinal study in Indonesia. *PLoS ONE* **2024**, *19*, e0295380. [[CrossRef](#)]
46. Demetriades, C.; Doumpas, N.; Teleman, A.A. Regulation of TORC1 in response to amino acid starvation via lysosomal recruitment of TSC2. *Cell* **2014**, *156*, 786–799. [[CrossRef](#)]
47. Beal, T.; Tumilowicz, A.; Sutrisna, A.; Izwardy, D.; Neufeld, L.M. A review of child stunting determinants in Indonesia. *Matern. Child Nutr.* **2018**, *14*, e12617. [[CrossRef](#)]
48. Butler, M.I.; Bastiaanssen, T.F.S.; Long-Smith, C.; Morkl, S.; Berding, K.; Ritz, N.L.; Strain, C.; Patangia, D.; Patel, S.; Stanton, C.; et al. The gut microbiome in social anxiety disorder: Evidence of altered composition and function. *Transl. Psychiatry* **2023**, *13*, 95. [[CrossRef](#)] [[PubMed](#)]
49. Garcia-Bonete, M.J.; Rajan, A.; Suriano, F.; Layunta, E. The Underrated Gut Microbiota Helminths, Bacteriophages, Fungi, and Archaea. *Life* **2023**, *13*, 1765. [[CrossRef](#)]
50. Dinh, D.M.; Ramadass, B.; Kattula, D.; Sarkar, R.; Braunstein, P.; Tai, A.; Wanke, C.A.; Hassoun, S.; Kane, A.V.; Naumova, E.N.; et al. Longitudinal analysis of the intestinal microbiota in persistently stunted young children in south India. *PLoS ONE* **2016**, *11*, e0155405. [[CrossRef](#)] [[PubMed](#)]

51. Thahir, A.I.A.; Gordon, A.; Salam, A. Does gut microbiome associate with the growth of infants? A review of the literature. *Enferm. Clin.* **2020**, *30*, 66–70. [\[CrossRef\]](#)
52. Zambruni, M.; Ochoa, T.J.; Somasunderam, A.; Cabada, M.M.; Morales, M.L.; Mitreva, M.; Rosa, B.A.; Acosta, G.J.; Vigo, N.I.; Riveros, M.; et al. Stunting is preceded by intestinal mucosal damage and microbiome changes and is associated with systemic inflammation in a cohort of Peruvian infants. *Am. J. Trop. Med. Hyg.* **2019**, *101*, 1009–1017. [\[CrossRef\]](#)
53. Surono, I.S.; Widiyanti, D.; Kusumo, P.D.; Venema, K. Gut microbiota profile of Indonesian stunted children and children with normal nutritional status. *PLoS ONE* **2021**, *16*, e02453991. [\[CrossRef\]](#)
54. Hoffman, D.J.; Campos-Ponce, M.; Taddei, C.R.; Doak, C.M. Microbiome, growth retardation and metabolism: Are they related? *Ann. Hum. Biol.* **2017**, *44*, 201–207. [\[CrossRef\]](#)
55. Krebs, N.F. Overview of Zinc Absorption and Excretion in the Human Gastrointestinal Tract. *J. Nutr.* **2000**, *130*, 1374S–1377S. [\[CrossRef\]](#)
56. Chen, X.; Jiang, Y.; Wang, Z.; Chen, Y.; Tang, S.; Wang, S.; Su, L.; Huang, X.; Long, D.; Wang, L.; et al. Alteration in Gut Microbiota Associated with Zinc Deficiency in School-Age Children. *Nutrients* **2022**, *14*, 2895. [\[CrossRef\]](#)
57. Danaei, G.; Andrews, K.G.; Sudfeld, C.R.; Fink, G.; McCoy, D.C.; Peet, E.; Sania, A.; Smith Fawzi, M.C.; Ezzati, M.; Fawzi, W.W. Risk Factors for Childhood Stunting in 137 Developing Countries: A Comparative Risk Assessment Analysis at Global, Regional, and Country Levels. *PLoS Med.* **2016**, *13*, e1002164. [\[CrossRef\]](#)
58. Ademas, A.; Adane, M.; Keleb, A.; Berihun, G.; Tesfaw, G. Water, sanitation, and hygiene as a priority intervention for stunting in under-five children in northwest Ethiopia: A community-based cross-sectional study. *Ital. J. Pediatr.* **2021**, *47*, 174. [\[CrossRef\]](#) [\[PubMed\]](#)
59. Andersson, M.; Braegger, C.P. The Role of Iodine for Thyroid Function in Lactating Women and Infants. *Endocr. Rev.* **2022**, *43*, 469–506. [\[CrossRef\]](#) [\[PubMed\]](#)
60. Zimmermann, M.B. The Effects of Iodine Deficiency in Pregnancy and Infancy. *Paediatr. Perinat. Epidemiol.* **2012**, *26*, 108–117. [\[CrossRef\]](#) [\[PubMed\]](#)
61. Velasco, I.; Bath, S.C.; Rayman, M.P. Iodine as essential nutrient during the first 1000 days of life. *Nutrients* **2018**, *10*, 290. [\[CrossRef\]](#)
62. Pirahanchi, Y.; Toro, F.; Jialal, I. *Physiology, Thyroid Stimulating Hormone*; StatPearls Publishing: Treasure Island, FL, USA, 2023.
63. Abbag, F.I.; Abu-Eshy, S.A.; Mahfouz, A.A.; Alsaleem, M.A.; Alsaleem, S.A.; Patel, A.A.; Mirdad, T.M.; Shati, A.A.; Awadalla, N.J. Iodine deficiency disorders as a predictor of stunting among primary school children in the aseer region, southwestern Saudi Arabia. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7644. [\[CrossRef\]](#)
64. Salazar, P.; Cisternas, P.; Codocedo, J.F.; Inestrosa, N.C. Induction of hypothyroidism during early postnatal stages triggers a decrease in cognitive performance by decreasing hippocampal synaptic plasticity. *Biochim. Biophys. Acta Mol. Basis Dis.* **2017**, *1863*, 870–883. [\[CrossRef\]](#)
65. Amano, I.; Takatsuru, Y.; Khairinisa, M.A.; Kokubo, M.; Haijima, A.; Koibuchi, N. Effects of Mild Perinatal Hypothyroidism on Cognitive Function of Adult Male Offspring. *Endocrinology* **2018**, *159*, 1910–1921. [\[CrossRef\]](#)
66. Stricker, R.; Echenard, M.; Eberhart, R.; Chevailler, M.-C.; Perez, V.; Quinn, F.A. Evaluation of maternal thyroid function during pregnancy: The importance of using gestational age-specific reference intervals. *Eur. J. Endocrinol.* **2007**, *157*, 509–514. [\[CrossRef\]](#)
67. Moog, N.K.; Entringer, S.; Heim, C.; Wadhwa, P.D.; Kathmann, N.; Buss, C. Influence of maternal thyroid hormones during gestation on fetal brain development. *Neuroscience* **2017**, *342*, 68–100. [\[CrossRef\]](#)
68. Sartika, R.A.D.; Sigit, F.S.; Purwanto, E.; Aris, N.; Marjan, A.Q.; Putra, W.K.Y.; Hastono, S.P. Association of birth weight with risk of diabetes mellitus in adolescence and early adulthood: Analysis of the Indonesian Family Life Survey. *Ann. Pediatr. Endocrinol. Metab.* **2023**, *28*, 267–274. [\[CrossRef\]](#) [\[PubMed\]](#)
69. Nakano, Y. Adult-onset diseases in low birth weight infants: Association with adipose tissue maldevelopment. *J. Atheroscler. Thromb.* **2020**, *27*, 397–405. [\[CrossRef\]](#) [\[PubMed\]](#)
70. Yokoyama, M.; Saito, I.; Ueno, M.; Kato, H.; Yoshida, A.; Kawamura, R.; Maruyama, K.; Takata, Y.; Osawa, H.; Tanigawa, T.; et al. Low birthweight is associated with type 2 diabetes mellitus in Japanese adults: The Toon Health Study. *J. Diabetes Investig.* **2020**, *11*, 1643–1650. [\[CrossRef\]](#) [\[PubMed\]](#)
71. Hill, D.J.; Hill, T.G. Maternal diet during pregnancy and adaptive changes in the maternal and fetal pancreas have implications for future metabolic health. *Front. Endocrinol.* **2024**, *15*, 1456629. [\[CrossRef\]](#)
72. Santos, C.D.D.L.; Clemente, A.P.G.; Martins, V.J.B.; Albuquerque, M.P.; Sawaya, A.L. Adolescents with mild stunting show alterations in glucose and insulin metabolism. *J. Nutr. Metab.* **2010**, *2010*, 943070. [\[CrossRef\]](#) [\[PubMed\]](#)
73. Jornayvaz, F.R.; Vollenweider, P.; Bochud, M.; Mooser, V.; Waeber, G.; Marques-Vidal, P. Low birth weight leads to obesity, diabetes and increased leptin levels in adults: The CoLaus study. *Cardiovasc. Diabetol.* **2016**, *15*, 73. [\[CrossRef\]](#) [\[PubMed\]](#)
74. Soliman, A.T.; Elzalabany, M.M.; Salama, M.; Ansari, B.M. Serum Leptin Concentrations During Severe Protein-Energy Malnutrition: Correlation with Growth Parameters and Endocrine Function. *Metabolism* **2000**, *49*, 819–825. [\[CrossRef\]](#) [\[PubMed\]](#)

75. Sahledengle, B.; Mwanri, L.; Petrucka, P.; Agho, K.E. Coexistence of Anaemia and Stunting among Children Aged 6–59 Months in Ethiopia: Findings from the Nationally Representative Cross-Sectional Study. *Int. J. Environ. Res. Public Health* **2023**, *20*, 6251. [CrossRef] [PubMed]
76. Sahledengle, B.; Petrucka, P.; Desta, F.; Sintayehu, Y.; Mesfin, T.; Mwanri, L. Childhood undernutrition mediates the relationship between open defecation with anemia among Ethiopian children: A nationally representative cross-sectional study. *BMC Public Health* **2024**, *24*, 1484. [CrossRef]
77. Iannotti, L.L.; Tielsch, J.M.; Black, M.M.; Black, R.E. Iron supplementation in early childhood: Health benefits and risks 1,2,3. *Am. J. Clin. Nutr.* **2006**, *84*, 1261–1276. [CrossRef]
78. Mara, D. The elimination of open defecation and its adverse health effects: A moral imperative for governments and development professionals. *J. Water Sanit. Hyg. Dev.* **2017**, *7*, washdev2017027. [CrossRef]
79. Wirth, J.P.; Rohner, F.; Woodruff, A.B.; Chiwile, F.; Yankson, H.; Koroma, A.S.; Russel, F.; Sesay, F.; Dominguez, E.; Petry, N.; et al. Anemia, micronutrient deficiencies, and malaria in children and women in Sierra Leone prior to the Ebola outbreak—Findings of a cross-sectional study. *PLoS ONE* **2016**, *11*, e0155031. [CrossRef]
80. Subramanian, S.V.; Balarajan, Y.; Ramakrishnan, U.; Özaltin, E.; Shankar, A.H. Anaemia in low-income and middle-income countries. *Lancet* **2011**, *378*, 2123–2158. [CrossRef]
81. Safari, O.; Ejtahed, H.-S.; Namazi, N.; Heshmat, R.; Arjmand, R.; Saleh, S.K.; Seif, E.; Shahsanai, A.; Motlagh, M.E.; Abdar, M.E.; et al. Association of short stature and obesity with cardio-metabolic risk factors in Iranian children and adolescents: The CASPIAN-V study. *J. Diabetes Metab. Disord.* **2021**, *20*, 1137–1144. [CrossRef] [PubMed]
82. Sekretariat Wakil Presiden Republik Indonesia. *Strategi Nasional Percepatan Pencegahan Anak Kerdil (Stunting)*; Sekretariat Wakil Presiden Republik Indonesia: Jakarta, India, 2019.
83. UNICEF. *Improving Child Nutrition, The Achievable Imperative for Global Progress*; UNICEF: New York, NY, USA, 2013.
84. World Health Organization. Reducing Stunting in Children: Equity Considerations for Achieving the Global Nutrition Targets 2025. Available online: <https://iris.who.int/handle/10665/260202> (accessed on 5 January 2025).
85. Sirajuddin; Sirajuddin, S.; Razak, A.; Ansariadi; Thaha, R.M.; Sudargo, T. The Intervention of Maternal Nutrition Literacy Has the Potential to Prevent Childhood Stunting: Randomized Control Trials. *J. Public Health Res.* **2021**, *10*, jphr-2021. [CrossRef] [PubMed]
86. World Health Organization. WHO Recommendations on Antenatal Care for a Positive Pregnancy Experience. Available online: https://www.who.int/reproductivehealth/publications/maternal_perinatal_health/anc-positive-pregnancy-experience/en/ (accessed on 5 January 2025).
87. Nisar, Y.B.; Aguayo, V.M.; Billah, S.M.; Dibley, M.J. Antenatal Iron-Folic Acid Supplementation Is Associated with Improved Linear Growth and Reduced Risk of Stunting or Severe Stunting in South Asian Children Less than Two Years of Age: A Pooled Analysis from Seven Countries. *Nutrients* **2020**, *12*, 2632. [CrossRef]
88. Dewey, K.G.; Arimond, M. Lipid-Based Nutrient Supplements: How Can They Combat Child Malnutrition? *PLoS Med.* **2012**, *9*, e1001314. [CrossRef]
89. Kawai, K.; Spiegelman, D.; Shankar, A.H.; Fawzi, W.W. Maternal multiple micronutrient supplementation and pregnancy outcomes in developing countries: Meta-analysis and meta-regression. *Bull. World Health Organ.* **2011**, *89*, 402–411. [CrossRef]
90. de Onis, M.; Dewey, K.G.; Borghi, E.; Onyango, A.W.; Blössner, M.; Daelmans, B.; Piwoz, E.; Branca, F. The World Health Organization’s global target for reducing childhood stunting by 2025: Rationale and proposed actions. *Matern. Child Nutr.* **2013**, *9*, 6–26. [CrossRef]
91. Bailén, M.; Bressa, C.; Martínez-López, S.; González-Soltero, R.; Lominchar, M.G.M.; Juan, C.S.; Larrosa, M. Microbiota Features Associated with a High-Fat/Low-Fiber Diet in Healthy Adults. *Front. Nutr.* **2020**, *7*, 583608. [CrossRef]
92. Ratnayani; Hegar, B.; Sunardi, D.; Fadilah, F.; Gunardi, H.; Fahmida, U.; Vidiawati, D. Association of Gut Microbiota Composition with Stunting Incidence in Children under Five in Jakarta Slums. *Nutrients* **2024**, *16*, 3444. [CrossRef] [PubMed]
93. Zhang, Y.; Wu, Q.; Wang, W.; van Velthoven, M.H.; Chang, S.; Han, H.; Xing, M.; Chen, L.; Scherpbier, R.W. Effectiveness of complementary food supplements and dietary counselling on anaemia and stunting in children aged 6–23 months in poor areas of Qinghai Province, China: A controlled interventional study. *BMJ Open* **2016**, *6*, e011234. [CrossRef]
94. Soofi, S.B.; Khan, G.N.; Sajid, M.; Hussainyar, M.A.; Shams, S.; Shaikh, M.; Ouma, C.; Azami, S.; Naeemi, M.; Hussain, A.; et al. Specialized nutritious foods and behavior change communication interventions during the first 1000 d of life to prevent stunting: A quasi-experimental study in Afghanistan. *Am. J. Clin. Nutr.* **2024**, *120*, 560–569. [CrossRef] [PubMed]
95. Zaidi, S.; Das, J.K.; Khan, G.N.; Najmi, R.; Shah, M.M.; Soofi, S.B. Food supplements to reduce stunting in Pakistan: A process evaluation of community dynamics shaping uptake. *BMC Public Health* **2020**, *20*, 1046. [CrossRef]
96. Adriani, M.; Wirjatmadi, B. The effect of adding zinc to vitamin A on IGF-1, bone age and linear growth in stunted children. *J. Trace Elem. Med. Biol.* **2014**, *28*, 431–435. [CrossRef]
97. Pekmez, C.T.; Dragsted, L.O.; Brahe, L.K. Gut microbiota alterations and dietary modulation in childhood malnutrition—The role of short chain fatty acids. *Clin. Nutr.* **2019**, *38*, 615–630. [CrossRef]

98. Barratt, M.J.; Nuzhat, S.; Ahsan, K.; Frese, S.A.; Arzamasov, A.A.; Alam Sarker, S.; Islam, M.M.; Palit, P.; Islam, R.; Hibberd, M.C.; et al. *Bifidobacterium infantis* treatment promotes weight gain in Bangladeshi infants with severe acute malnutrition. *Sci. Transl. Med.* **2022**, *14*, eabk1107. [\[CrossRef\]](#)
99. Nuzhat, S.; Hasan, S.M.T.; Palit, P.; Islam, R.; Mahfuz, M.; Islam, M.M.; Alam, A.; Flannery, R.L.; Kyle, D.J.; Sarker, S.A.; et al. Effects of probiotic and synbiotic supplementation on ponderal and linear growth in severely malnourished young infants in a randomized clinical trial. *Sci. Rep.* **2023**, *13*, 1845. [\[CrossRef\]](#)
100. Fallah, R.; Du, L.; Braverman, L.E.; He, X.; Segura-Harrison, M.; Yeh, M.W.; Pearce, E.N.; Chiu, H.K.; Mittelman, S.D.; Leung, A.M. Iodine Nutrition in Weaning Infants in the United States. *Thyroid* **2019**, *29*, 573–576. [\[CrossRef\]](#)
101. Wang, L.; Huo, J.; Wei, Y.; Tang, Y.; Sun, J.; Huang, J. Yingyangbao Reduced Anemia among Infants and Young Children Aged 6–23 Months When Delivered through a Large-Scale Nutrition Improvement Program for Children in Poor Areas in China from 2015 to 2020. *Nutrients* **2023**, *15*, 2634. [\[CrossRef\]](#) [\[PubMed\]](#) [\[PubMed Central\]](#)
102. Khan, A.; Ul-Haq, Z.; Fazid, S.; Fatima, S.; Muhammad, N.; Ahmed, J.; Manoharadas, S.; Safi, S.Z.; Habib, I.; Garzon, C.; et al. Effectiveness of locally produced ready to use supplementary food on hemoglobin, anthropometrics, and plasma micronutrients concentrations of 6 to 23 months age children: A non-randomized community-based trial from Pakistan. *Front. Nutr.* **2023**, *10*, 1176778. [\[CrossRef\]](#) [\[PubMed\]](#)
103. Stewart, C.P.; Fernald, L.C.H.; Weber, A.M.; Arnold, C.; Galasso, E. Lipid-Based Nutrient Supplementation Reduces Child Anemia and Increases Micronutrient Status in Madagascar: A Multiarm Cluster-Randomized Controlled Trial. *J. Nutr.* **2020**, *150*, 958–966. [\[CrossRef\]](#)
104. Anderson, L.M.; Shinn, C.; Fullilove, M.T.; Scrimshaw, S.C.; Fielding, E.J.; Normand, J.; Carande-Kulis, V.G. The effectiveness of early childhood development programs. *Am. J. Prev. Med.* **2003**, *24*, 32–46. [\[CrossRef\]](#)
105. World Health Organization. *Everybody Business: Strengthening Health Systems to Improve Health Outcomes: WHO's Framework for Action*; WHO Press: Geneva, Switzerland, 2007.
106. Ocansey, M.E.; Adu-Afarwuah, S.; Kumordzie, S.M.; Okronipa, H.; Young, R.R.; Tamakloe, S.M.; Oaks, B.M.; Arimond, M.; Dewey, K.G.; Prado, E.L. The association of early linear growth and haemoglobin concentration with later cognitive, motor, and social-emotional development at preschool age in Ghana. *Matern. Child Nutr.* **2019**, *15*, e12834. [\[CrossRef\]](#) [\[PubMed\]](#)
107. Mustakim, M.R.D.; Irawan, R.; Irmawati, M.; Setyoboedi, B. Impact of Stunting on Development of Children between 1–3 Years of Age. *Ethiop. J. Health Sci.* **2022**, *32*, 569. [\[CrossRef\]](#)
108. Gizaw, Z.; Yalew, A.W.; Bitew, B.D.; Lee, J.; Bisesi, M. Stunting among children aged 24–59 months and associations with sanitation, enteric infections, and environmental enteric dysfunction in rural northwest Ethiopia. *Sci. Rep.* **2022**, *12*, 19293. [\[CrossRef\]](#)
109. Lefebo, B.K.; Kassa, D.H.; Tarekegn, B.G. Factors associated with stunting: Gut inflammation and child and maternal-related contributors among under-five children in Hawassa City, Sidama Region, Ethiopia. *BMC Nutr.* **2023**, *9*, 54. [\[CrossRef\]](#)
110. Henriques, A.; Teixeira, V.; Cardoso, H.F.V.; Azevedo, A. The influence of stunting on obesity in adulthood: Results from the EPIPorto cohort. *Public Health Nutr.* **2018**, *21*, 1819–1826. [\[CrossRef\]](#)
111. Rolfe, E.D.L.; de França, G.V.A.; Vianna, C.A.; Gigante, D.P.; Miranda, J.J.; Yudkin, J.S.; Horta, B.L.; Ong, K.K. Associations of stunting in early childhood with cardiometabolic risk factors in adulthood. *PLoS ONE* **2018**, *13*, e0192196. [\[CrossRef\]](#)
112. Mutumba, R.; Mbabazi, J.; Pesu, H.; Greibe, E.; Olsen, M.F.; Briend, A.; Mølgaard, C.; Ritz, C.; Mupere, E.; Filteau, S.; et al. Micronutrient Status and Other Correlates of Hemoglobin among Children with Stunting: A Cross-Sectional Study in Uganda. *Nutrients* **2023**, *15*, 3785. [\[CrossRef\]](#)
113. Mbabazi, J.; Pesu, H.; Mutumba, R.; McCray, G.; Ritz, C.; Filteau, S.; Briend, A.; Mupere, E.; Grenov, B.; Friis, H.; et al. Predictors of change in early child development among children with stunting: Secondary analysis of a randomized trial in Uganda. *PLoS Glob. Public Health* **2024**, *4*, e0003456. [\[CrossRef\]](#) [\[PubMed\]](#)
114. Haque, A.; Wahid, B.Z.; Farzana, F.D.; Ahmed, S.M.T.; Ali, M.; Naz, F.; Rahman, S.S.; Siddiqua, T.J.; Faruque, A.S.G.; Choudhury, N.; et al. Influence of the Suchana intervention on exclusive breastfeeding and stunting among children aged under 6 months in the Sylhet region of Bangladesh. *Matern. Child Nutr.* **2023**, *19*, e13535. [\[CrossRef\]](#)
115. Hadi, H.; Fatimatasari, F.; Irwanti, W.; Kusuma, C.; Alfiana, R.D.; Asshiddiqi, M.I.N.; Nugroho, S.; Lewis, E.C.; Gittelsohn, J. Exclusive breastfeeding protects young children from stunting in a low-income population: A study from eastern Indonesia. *Nutrients* **2021**, *13*, 4264. [\[CrossRef\]](#)
116. Ashraf, K.; Huda, T.M.; Ikram, J.; Ariff, S.; Sajid, M.; Khan, G.N.; Umer, M.; Ahmed, I.; Dibley, M.J.; Soofi, S.B. The Effectiveness of Nutritional Interventions Implemented through Lady Health Workers on the Reduction of Stunting in Children under 5 in Pakistan: The Difference-in-Difference Analysis. *Nutrients* **2024**, *16*, 2149. [\[CrossRef\]](#)
117. Mayén, V.A.; Ogunlusi, A.; Wright, C.M.; Garcia, A.L. Childhood stunting and micronutrient status unaffected by RCT of micronutrient fortified drink. *Matern. Child Nutr.* **2022**, *18*, e13256. [\[CrossRef\]](#)
118. Roberts, S.B.; Franceschini, M.A.; Silver, R.E.; Taylor, S.F.; De Sa, A.B.; C6, R.; Sonco, A.; Krauss, A.; Taetzsch, A.; Webb, P.; et al. Effects of food supplementation on cognitive function, cerebral blood flow, and nutritional status in young children at risk of undernutrition: Randomized controlled trial. *BMJ* **2020**, *370*, m2397. [\[CrossRef\]](#) [\[PubMed\]](#)

119. Black, M.M.; Fernandez-Rao, S.; Nair, K.M.; Balakrishna, N.; Tilton, N.; Radhakrishna, K.V.; Ravinder, P.; Harding, K.B.; Reinhart, G.; Yimgang, D.P.; et al. A Randomized Multiple Micronutrient Powder Point-of-Use Fortification Trial Implemented in Indian Preschools Increases Expressive Language and Reduces Anemia and Iron Deficiency. *J. Nutr.* **2021**, *151*, 2029–2042. [[CrossRef](#)] [[PubMed](#)]
120. Li, J.; Liu, J.-X.; Shen, X.-L.; Wang, Y.-Q.; Yan, C.-H. A national survey of iodine nutrition in children aged 3–6 years in China and its relationship with children's physical growth. *Matern. Child Nutr.* **2024**, *20*, e13685. [[CrossRef](#)]
121. Ferede, A.; Wordofa, M.A.; Belachew, T. Behavior change intervention to sustain iodide salt utilization in households in Ethiopia and study of the effect of iodine status on the growth of young children: Community trial. *PeerJ* **2024**, *12*, e16849. [[CrossRef](#)]
122. Ansuya; Nayak, B.S.; Unnikrishnan, B.; Shashidhara, Y.N.; Mundkur, S.C. Effect of nutrition intervention on cognitive development among malnourished preschool children: Randomized controlled trial. *Sci. Rep.* **2023**, *13*, 10636. [[CrossRef](#)]
123. Luoto, J.E.; Garcia, I.L.; Aboud, F.E.; Singla, D.R.; Fernald, L.C.H.; Pitchik, H.O.; Saya, U.Y.; Otieno, R.; Alu, E. Group-based parenting interventions to promote child development in rural Kenya: A multi-arm, cluster-randomised community effectiveness trial. *Lancet Glob. Health* **2021**, *9*, e309–e319. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.