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IMPACT OF SOY PROTEIN-BASED READY-TO-USE FOODS (RUFs) AS COMPLEMENTARY FEEDING ON GROWTH DEFICITS IN CHILDREN UNDER FIVE IN LOW AND MIDDLE-INCOME COUNTRIES: A REVIEW

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Abstract: The study examined the efficacy of soy-based Ready-to-Use Foods (RUFs) in improving the nutritional status of children under five with growth deficits in Low- and Middle-Income Countries (LMICs) in light of the World Health Organisation's (WHO) projection of 127 million affected children by 2025. Through searches of databases, including ScienceDirect, PubMed, and ProQuest, from 2013 to 2023, 25 relevant studies were identified and rigorously evaluated for Risk of Bias (RoB). Data extraction focused on study design, sample size, intervention details (duration, dosage, and type of soy protein-based food), and outcomes related to nutritional status. Findings suggest that soy-based RUFs promise to mitigate worsening growth deficits and improve anthropometric outcomes such as Height-for-Age z-scores (HAZ) and Mid-Upper Arm Circumference (MUAC). 23 studies reported a significant improvement in nutritional status, while two showed no significant impact. Consequently, these studies were conducted across diverse regions, mostly focusing on countries in sub-Saharan Africa and Asia. The foods used in these interventions included fortified cereals, Ready-to-Use Supplementary or Therapeutic Foods (RUSF/RUTFs), high-protein biscuits, enriched flours, porridge/soup, and therapeutic milk. However, some studies report limited or insignificant results influenced by variations in study design, intervention duration, and contextual factors. The interventions, often combined with locally available crops, exhibited high child acceptance due to enhanced sensory qualities. Despite their potential, the sustainability of donor-driven RUF programs remains challenging, underscoring the need for locally sourced and culturally tailored solutions. Future research should address these disparities to promote sustainable child development in LMICs.

Keywords: Complementary feeding, soy protein, ready-to-use food, growth deficits, low- and middle-income countries.

Introduction

Growth deficits in children, resulting from inadequate nutrition or health issues, remain a significant global health challenge, hindering their ability to achieve expected height and physical development (Leroy & Frongillo, 2019). Evidence suggests that children with growth deficits are more likely to experience cognitive disorder deficits, educational challenges, and diminished economic productivity in adulthood (Sudfeld *et al*., 2015). Building upon the World Health Organisation's (WHO) projections, it is estimated that if current patterns are maintained, approximately 127 million children under five will be affected by growth deficits by 2025 (WHO, 2014).

Moreover, malnutrition is widespread worldwide in Low- and Middle-Income Countries (LMICs) (Kureishy *et al*., 2017). Various interventions have been implemented to tackle this issue to improve the nutritional status of these at-risk youth. These initiatives span multiple sectors, from nutrition and health care to Water, Sanitation, and Hygiene (WASH) and early childhood development (Patlán-

Hernández *et al*., 2022). In particular, proper complementary feeding practices are essential to meet the growing nutritional needs of infants and young children, thereby preventing growth deficits (Harrison *et al*., 2023). Inadequate complementary feeding—either due to poor dietary quality or insufficient quantity—can lead to nutrient deficiencies and subsequent growth faltering (Sudfeld *et al*., 2015).

Soy protein-based Ready-to-Use Foods (RUFs) are specially formulated products designed to provide high-quality protein and essential nutrients required for child growth and development (Fetriyuna *et al*., 2021). These foods are often fortified with vitamins and minerals such as iron, zinc, and vitamin A, which are critical for preventing micronutrient deficiencies (Greiner, 2014; Tam *et al*., 2020). Soy protein is one of the high-quality protein types with a Protein Digestibility Corrected Amino Acid Score (PDCAAS) of 1, which is relatively similar to animal protein values such as meat and milk (Qin *et al*., 2022). Furthermore, soy-based RUFs are typically shelf-stable and do not require refrigeration, making them suitable for use in diverse and resource-limited settings (Greiner, 2014). Therefore, it is vital to assess how effective soy protein-based food can be when mitigating poor nutrition among those affected by growth deficits.

Despite the growing interest in plant-based interventions for addressing malnutrition, particularly in LMICs, there is still a lack of research on the impact of soy protein RUFs on various growth parameters (Drewnowski, 2024). Meanwhile, many studies have explored the role of RUFs in general and few have disaggregated the effects of soy protein-based formulations on height, weight, and other nutritional indicators in children with growth deficits. Additionally, evidence is limited on these interventions' long-term sustainability and cultural acceptability across different socioeconomic contexts.

This review, therefore, seeks to fill these gaps by establishing the feasibility of soy protein-based RUFs in enhancing the nutritional status of under five children with growth deficiencies in LMICs. In turn, it summarises the findings of multiple studies to explore the effects on structural measures such as height and weight, as well as other anthropometric and nutritional parameters relevant to the outcomes. In addition, the review also provides information on the acceptance aspects, implementation of the programs and possibility of incorporating these interventions into local diets. In this way, by presenting the results of this review, we hope to contribute to a better understanding of the possibilities of using soy protein-based RUFs in the fight against malnutrition. It further improves the direction for solving growth issues in resource-limited settings.

Methods

This review adhered to the guidelines set out by the modified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page *et al*., 2021). In October-December 2023, a comprehensive literature search was conducted across three primary databases, ScienceDirect, PubMed, and ProQuest, reviewing literature published between 2013 and 2023. The search strategy employed combined various synonyms using the Medical Subject Headings (MeSH) method for key terms such as [(soy ready-to-use food) AND (growth deficits) OR (stunting) OR (malnutrition)].

Note that research papers were chosen using specific inclusion criteria: (1) Participants were children under five years old from LMICs who were identified as having growth deficits, including malnourished and stunted growth; (2) studies included interventions involving soy-based foods, whether locally sourced or processed; (3) the focus of the studies was on investigating stunting or malnutrition; (4) the review included Randomised Controlled Trials (RCTs), quasi-experimental studies, and cohort studies that investigated the impact of soy protein-based RUFs on the nutritional status of children under five with growth deficits in

LMICs; (5) the papers were original research articles; (6) they were written in English; and (7) they were openly accessible.

Meanwhile, exclusion criteria for studies in this analysis were: (1) Interventions targeting breastfeeding mothers and infants; (2) experimental nutritional supplements that do not include soy protein as an ingredient; (3) studies focusing on specific groups of children with severe illnesses or health conditions such as cancer, genetic, immune system or metabolic disorders, severe head injuries, and food allergic; (4) non-original research articles (e.g., reviews, commentaries, editorials); (5) research papers that were not freely available in their complete form online or do not allow open access to the general public; and (6) studies not available in the English language.

The quality and Risk of Bias (RoB) of included studies were assessed using RoB Tools such as the Cochrane RoB tool for randomised trials. Studies will be categorised based on the following criteria (Sterne *et al*., 2019; Higgins *et al*., 2022):

(a) Low RoB: Studies are assessed as low risk if all domains in the RoB tool (such as randomisation process, deviations from intended interventions, missing outcome data) were judged to be at low RoB, i.e., will not result in over/underestimation of intervention effect.

(b) Moderate RoB: Studies were assigned to moderate risk if one or more domains have concerns about bias. Overall, this is not considered significant enough for the study results to be seriously downgraded. This can happen when there are doubts about how participants were randomised or if the study lacks an outcome data point (but it is not that critical to cast a shadow on the results).

(c) High RoB: Studies were labelled high risk for bias when they have major flaws that could seriously affect their results. This might happen if the study was not set up properly, too many participants were lost, only some findings were reported, or there were other big problems with how it was done. When a study has these issues, it is hard to trust what it claims to have found.

In addition, the relevance of each publication's content to the research objectives was evaluated. This included assessing whether the study provided results related to soy protein-based food interventions in the research subjects. A pilot test for data extraction was performed on a subset of studies to refine the extraction process and ensure consistency. The extraction focused on key elements such as study design, sample size, intervention specifics including duration, dosage, and type of soy protein-based food, and outcome measures related to nutritional status. Note that two reviewers independently performed the data extraction. When disagreements arose, they were resolved through discussion or consulting a third reviewer, ensuring the accuracy of the extracted information.

Results

Screening and Studies Selection

Based on searches conducted with predefined keywords, the results from each database suggested significant variations, as displayed in Figure 1. ScienceDirect contributed 10,275 studies while PubMed contributed 1,528 studies. ProQuest provided the highest number of studies, with 58,374. Thus, 70,177 studies were found from various sources. During the screening stage, 356 studies were discovered as duplicates and 32 studies were identified as research of particular interest and removed. Subsequently, of the 69,691 titles screened, 98 studies met the criteria and proceeded to the further assessment stage. Of these 98 studies, six did not meet the age criteria, 61 did not meet the inclusion criteria, seven did not fall under the food intervention category, nine did not original research, and 12 did not meet the required outcome criteria. Finally, 25 studies met the criteria and will be analysed further. This stage was conducted to ensure the relevance, quality, and compliance with the research criteria of the selected studies. However, outcome measures across the studies vary due to differences in study objectives and methodologies.

Study Characteristics

The 25 studies that met the criteria in terms of inclusion and exclusion included 17,840 participants from different LMICs in Asia and Africa. These studies encompassed various research designs, participant demographics, trial registration or ethical approval numbers, and study limitations, as detailed in Table 1. Moreover, several studies reported data on multiple outcome measures: 13 focused on anthropometric status, eight on nutritional status, three on acceptability or sensory evaluation, and three on other outcomes such as cognitive and psychomotor developments. The interventions' duration varies, ranging from the shortest period of 12 days to the longest of 24 months. Additionally, Table 2 provides an overview of the type of soy interventions and the corresponding study findings.

Risk of Bias

The findings from the RoB evaluation are displayed in Figure 2, covering six bias domains. Each domain was labelled as low (+), some concern (?), or high (-). Eight studies were determined to have a low overall bias risk, six were classified as having a high bias risk, and 11 raised some concerns regarding bias. In the category of the randomisation process, nearly all studies, except two were defined as low RoB. For allocation concealment (selection bias), nine studies were rated as having some concern. One study had a high RoB and 15 had a low RoB.

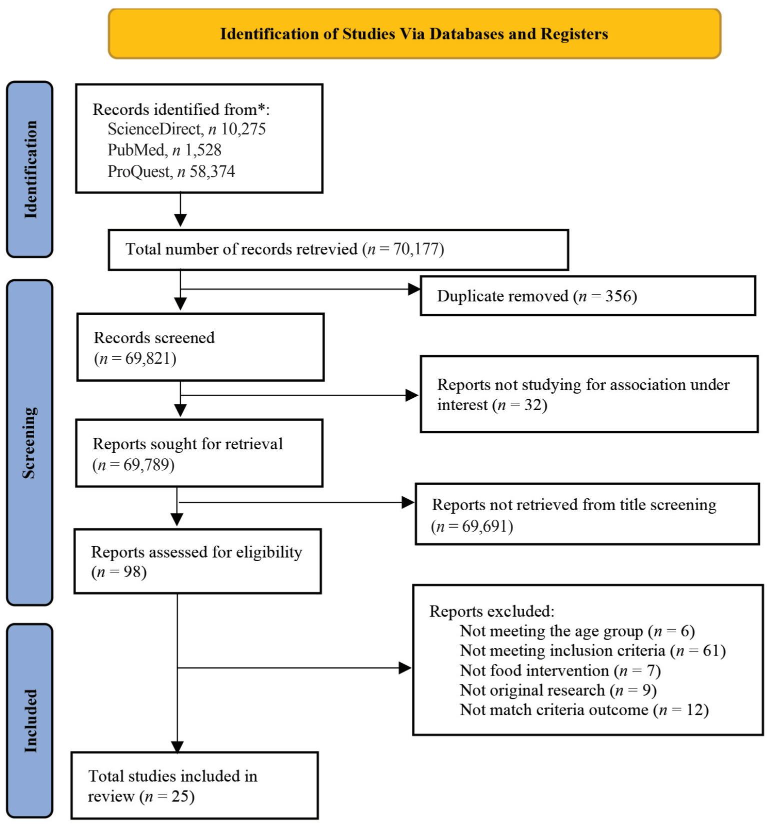

Figure 1: PRISMA flow diagram of selection of eligible studies

Table 1: General characteristics of the included studies

No.	Author	Year	Study Country	Study Design	Participant Numbers	Age (Months)	Trial Registry/Ethical Clearance No.	Study Limitation
1	Chang *et al*.	2013	Southern Malawi	RCT	1967	6-59	NCT00998517	The study was conducted in an area with specific climatic conditions.
2	Irena *et al*.	2013	Zambia	CRT	1927	6-59	NR	It was not possible to blind the type of RUTF allocated from the staff or caregivers.
3	Nga *et al*.	2013	Vietnam	RCT	67	36-59	NR	NR
4	Niyibituronsa *et al*.	2014	Rwanda	RCT	30	6-59	NR	NR
5	Thakwalakwa *et al*.	2014	Malawi Republic	RCT	188	8-18	NCT00131209	NR
6	Mangani *et al*.	2015	Malawi Republic	RCT	188	6-18	NCT00524446	NR
7	Christian *et al*.	2015	Bangladesh	CRT	5536	6-18	NR	The trial was not blinded and the supplementation did not continue until the age of 24 months.
8	Hemsworth *et al*.	2015	Malawi Republic	RCT	172	6, 9,5	NCT00945698	There was a potential shift of energy from particular complementary foods.
9	Ronoh *et al*.	2017	Kenya	RCT	NR	36-60	NR	NR
10	Bahwere *et al*.	2017	Malawi Republic	RCT	225	6-23, 24-59	PACTR201505001101224	Limited budgets decrease the scope and long-term viability of treatment initiatives.
11	Sato *et al*.	2018	Malawi Republic	RCT	499	6-23, 24-59	PACTR201505001101224	The timing of the subjects' meals was not controlled when blood samples were taken
12	Cichon *et al*.	2018	Burkina Faso	RCT	1609	6-23	ISRCTN42569496	The ingredients differed between products, and an unsupplemented control group was lacking.
13	Akomo *et al*.	2019	Malawi Republic	RCT	389	6-59	PACTR201505001101224	Some methodological limitations are related to indicator measurement.
14	Hossain *et al*.	2019	Bangladesh	RCT	260	6-59	NCT01634009	NR

15	Kajjura *et al.*	2019	Uganda	CRT	220	6-18	REC/11353/394	NR
16	Smuts *et al.*	2019	South Africa	RCT	750	6-12	NCT01845610	The study had a high dropout rate and was not fully blinded.
17	Masuda and Chitundu	2019	Zambia	RCT	501	6-18	NCT03523182	Unblinded trial and the products may have been shared by other household members.
18	Azimi *et al.*	2020	Iran	RCT	100	24-59	IRCT2017021315536N6	No examination of blood biomarkers and no reports of dietary intake from regular foods.
19	Olsen *et al.*	2020	Burkina Faso	RCT	1609	6-23	ISRCTN42569496	Not include an unsupplemented control group.
20	Othoo *et al.*	2021	Kenya	RCT	240	6-23	PACTR202004842786087	NR
21	Molto *et al.*	2022	Cambodia	CRT	386	6-24	NR	Single-centre retrospective design with missing data and the absence of various key data points.
22	Chabibah *et al.*	2023	Indonesia	RCT	40	12-36	076/EP-FKIK-UMY/ II/2017	25% of toddlers in each group were lost to follow-up.
23	Kiio *et al.*	2023	Kenya	CRT	346	6-36	PACTR201907492232376	The failure to use trace-element-free vacutainers.
24	Lalèyè *et al.*	2023	Benin Republic	RCT	289	6-59	IRB00006860	The protocol primarily aims to induce weight gain rather than achieve a clear resolution of MAM.
25	Rachmadewi *et al.*	2023	Indonesia	RCT	302	6-59	KE/FK/137/EC/2020	NR

RCT (Randomised Controlled Trial), CRT (Clustered Randomised Trial), NR (Not Reported).

Table 2: Data extraction of the studies

No.	Authors	Year	Duration of Intervention (Months)	Type of Soy Intervention	Outcome Measures	Findings
1	Chang *et al*.	2013	4 (12 weeks)	CSB (Corn-Soy Blend plus milk and oil), soy RUSF, soy/whey RUSF	Nutrition risk status	Children treated with soy/whey RUSF (67%) were better nourished than those treated with CSB++ (62%) or soy RUSF (59%).
2	Irena *et al*.	2013	6	Milk-free soy–maise–sorghum based RUTF (SMS-RUTF) and P-RUTF (Peanut based) (200 kcal/day)	Recovery rate	In the intention-to-treat analysis, SMS-RUTF had a recovery rate of 53.3% and P-RUTF had a rate of 60.8%. In the per-protocol analysis, the rates were 77.9% for SMS-RUTF and 81.8% for P-RUTF.
3	Nga *et al*.	2013	0.5	Soy and green bean-based RUTF (1 sachet (500-530 kcal) of RUTF/meal, 1,000 kcal/day) (two times meal/day)	Acceptability, nutritional status	The children showed significant improvement in their nutritional status, accepted the RUTF well, and increased WHZ and HAZ scores.
4	Niyibituronsa *et al*.	2014	3	Soybean milk (250 ml), soybean-flour-based soup (250 ml) (125 kcal)	Weight gain	The mean weight gain of children using soybean milk and soybean soup was 0.9 (±0.9) and 0.3 (±0.2), respectively.
5	Thakwalakwa *et al*.	2014	9 (weeks)	Corn-soy-blend (CSB) (71 g/284 kcal/day) and LNS (Lipid-based Nutrient Supplement) (43 g/ 220 kcal/day)	Energy, macro and micronutrient intakes	LNS might be a better choice than CSB for supplementing underweight children due to its ability to provide higher energy intake.
6	Mangani *et al*.	2015	12	Soy-based-LNS (Lipid-based Nutrient Supplements): 54 g/day	Length-for-age, weight-for-age	The length-for-age increased by 0.2, weight-for-age increased by 110 g, and severe stunting was reduced.
7	Christian *et al*.	2015	12	Chickpea and rice-lentil-based RUF and fortified blended food (soy-wheat blend++, WSB++)	Length, Length-for-Age z-score (LAZ)	The average length and Length-for-Age Z-score (LAZ) at 18 months were increased by approximately 0.27 to 0.30 cm and 0.07 to 0.10, respectively.

8	Hemsworth *et al*.	2015	13	LNSs with milk powder and without milk powder (soybean oil based) (10-40 g/day)	Energy and macronutrient intakes	Supplementing with LNSs in doses ranging from 10 to 40 g/day boosts energy and macronutrient intake among 9 to 10 month old infants by up to 10 kcal/day.
9	Ronoh *et al*.	2017	6	Soybean-fortified porridges: 300 ml/day	Weight gain	Children who consumed the maise-soybean blend gained 1.77 kg while those who consumed the maise-sorghum-soybean blend gained 0.62 kg.
10	Bahwere *et al*.	2017	3	FSMS-RUTF (Soya maise sorghum with no milk), MSMS-RUTF (Soya maise sorghum with low milk), PM-RUTF (Peanut and dried skim milk based)	Efficacy of RUTF (recovery rates, haemoglobin and body iron stores)	FSMS-RUTF without milk effectively treats severe acute malnutrition in children aged 6 to 23 and 24 to 59 months. Additionally, it demonstrates superior efficacy in correcting iron deficiency anaemia compared to PM-RUTF.
11	Sato *et al*.	2018	3	FSMS-RUTF (Soya maise sorghum with no milk), MSMS-RUTF (Soya maise sorghum with low milk), PM-RUTF (Peanut and dried skim milk based) (200 kcal/day)	Plasma EAA (essential amino acid) levels	Children treated with FSMS-RUTF and MSMS-RUTF produced good plasma levels of essential amino acids and no less than those treated with PM-RUTF [17.8% (1.6, 34.1) and 13.6% (-2.8, 29.9)].
12	Cichon *et al*.	2018	3 (12 weeks)	LNS or CSB 500 kcal/day (containing DS/SI)	Haemoglobin, iron status, and inflammation	Children who were given LNS showed improved haemoglobin and iron levels compared to those who received CSB. However, the prevalence of anaemia remained high.
13	Akomo *et al*.	2019	3 (weeks)	FSMS-RUTF (Soya maise sorghum with no milk), MSMS-RUTF (Soya maise sorghum with low milk), PM-RUTF (Peanut and dried skim milk based)	Anaemia and iron deficiency (ID)	FSMS-RUTF is more effective in treating anaemia and correcting Body Iron Stores (BIS) in this population than PM-RUTF.

14	Hossain *et al*.	2019	39/44 (days)	SPI based-RUTF (30 g of RUTF for ≤ 7 kg body weight group and 45 g of RUTF for ≥ 7 kg group)	Weight-for age, WHZ, MUAC, body composition	There was an increase of 0.698 g in weight, 1.12 g in Weight-for-Height z-score (WHZ), and 0.9 mm in MUAC.
15	Kajjura *et al*.	2019	3	Malted sorghum-based porridge (MSBP) (mixed of malt, sorghum, soy, maise) and CSB+ (maise and soy micronutrient fortified blend)	Anthropometric status and haemoglobin levels	Supplementation with MSBP resulted in a satisfactory recovery rate compared to CSB+ in managing Infants and Young Children (IYC) with Moderate Acute Malnutrition (MAM). However, the recovery rate with MSBP was higher than CSB+.
16	Smuts *et al*.	2019	6 (26 weeks)	SQ-LNS, SQ-LNS-plus (soy and dairy-based), no supplement (2 sachet/day = 20 g)	Linear growth, psychomotor development, iron status, morbidity	SQ-LNS-plus improved LAZ score at 8 and 10 months but not at 12 months, as well as locomotor development and parent rating scores. It did not affect the weight-for-age z score. Both products raised haemoglobin levels and reduced fever and coughing but increased diarrhoea, vomiting, and rash/soreness.
17	Masuda and Chitundu	2019	12	Spirulina powder and soya flour porridge blend (10 g/day)	HAZ, WAZ, morbidity, and motor development	The SP and CON groups had similar weight gain, suggesting spirulina had little effect on the weight of malnourished infants. However, adding spirulina to complementary foods at home helped prevent upper respiratory infections and improve motor milestone achievement.
18	Azimi *et al*.	2020	6	SPI based-RUSF	Weight and height, WHZ, and BMI	Weight increase (1.44 + -0.38 kg) and BMI (1.2 + -0.47 kg/m^2), daily height increase (0.027), and WHZ improvement (1.18 + -0.41).
19	Olsen *et al*.	2020	12 and 24	Milk and SPI based-LNS or CSB (92 g LNS or 120 g CSB) (500 kcal/day)	Gross and fine motor language development	Milk protein showed greater benefits for language and fine motor development compared to soy isolate/dehulled.
20	Othoo *et al*.	2021	6	Spirulina Corn Soy Blend (SCSB), CSB, and placebo flour (200 ml, 3 times a day, 700 kcal)	Iron deficiency anaemia (IDA)	Treating IDA with SCSB compared to CSB and placebo resulted in quicker reversal and a higher number of recoveries from IDA.

21	Molto *et al*.	2022	18	LNS (Nutributter, Plumpy Soy)	HAZ and MUAC	Increasing HAZ (0.1-0.3) results in higher MUAC in children with intervention (-0.75) than in control (-1.1).
22	Chabibah *et al*.	2023	24 (days)	Three pieces of biscuits (90 kcal), soy milk fortified with 0.32 moringa leaf (100 CCs)	Body weight and height	Significant difference in average body weight between the intervention and control groups. However, there was no significant difference in mean height between the two groups.
23	Kiio *et al*.	2023	6	CSB- MNP-A (with zinc), CSB-MNP-B (no zinc), CSB-MNP-C (only zinc), Control (standard CSB) (63,75 g)	Serum zinc status	The average increase in serum zinc concentration was significantly greater (p = 0.024) in the CSB-MNP-A group (18.7 ± 2.1 µg/dL) compared to the control group (11.8 ± 2.6 µg/dL). Additionally, it was found that MNPs are not equivalent to CSB within the ± 20% bioequivalence limit.
24	Lalèyè *et al*.	2023	12 (days)	50 g FARIFORTI flour porridge (mixed of corn flour, soybean malted sorghum, shelled and roasted peanuts, baobab pulp, and dried fried fish)	Sensory evaluation, weight gain	Mothers (97%) and children (98%) approved of FARIFORTI flour. FARIFORTI porridge increased carbohydrate and iron intake in children, resulting in a weight gain of 35.45 g per day per child.
25	Rachmadewi *et al*.	2023	8 (weeks)	Standard RUTF (CON), RUTF-soybean (SOY), peanuts (PEA), and mungbean (MUN1, MUN2) with 1.5-4 sachets depending on body weight	Weight gain and product acceptability	Younger kids preferred MUN2 and PEA products more than older ones. All children, whether CON or SOY RUTF, gained over 2 g/kg/day of body weight while those with other RUTF products gained 1.6 g/kg/day, with no significant difference ($p > 0.05$).

Regarding blinding of participants and personnel, five studies were at high risk, eight raised concerns, and 12 had low risk. Three studies exhibited a high RoB in the blinding of outcome assessment, another 10 had some concerns, and 12 had low RoB. Regarding incomplete outcome (attrition bias), five studies had a high RoB and the rest had a low RoB. Most studies indicated a low RoB for selective reporting except for one study, which was rated as having "high risk" in this domain. Figure 3 illustrates the overall RoB summarised as percentages across different domains, visually depicting the proportions of studies with various levels of RoB. Specifically, discrepancies between reviewers were resolved by consulting a third reviewer to reach a consensus, ensuring consistency and reliability in the RoB assessment.

Effect of RUFS on Anthropometric Indices

Studies listed indicate that soy-based food interventions tend to yield positive results in improving children's anthropometric status. For instance, a study in Tehran, Iran, discovered that children with mild to moderate malnutrition received locally produced RUFs consisting of a mixture of Isolated Soy Protein (ISP) and other ingredients (15% protein per 100 g). For eight weeks, they experienced an average weight gain of 1.44 (± 0.380) kg and a BMI increase of 1.20 (± 0.470) kg/m^2 compared to the control group on a normal diet. Additionally, the RUSF group showed a greater daily height growth of 0.027 cm after four weeks of intervention (Azimi *et al*., 2020).

In Hanoi, Vietnam, it also determined that children with severe acute malnutrition consumed locally produced soy and mung bean-based RUTF with other ingredients (15% protein per 100 g). For four weeks, they demonstrated significant improvements in nutritional status, with an average weight gain of 0.64 (± 0.270) kg and a height increase of scores by 0.34, 0.05, and 0.48, respectively (P < 0.010 for all). Additionally, MUAC increased by 0.50 (± 0.300) cm during the intervention period (Nga *et al*., 2013).

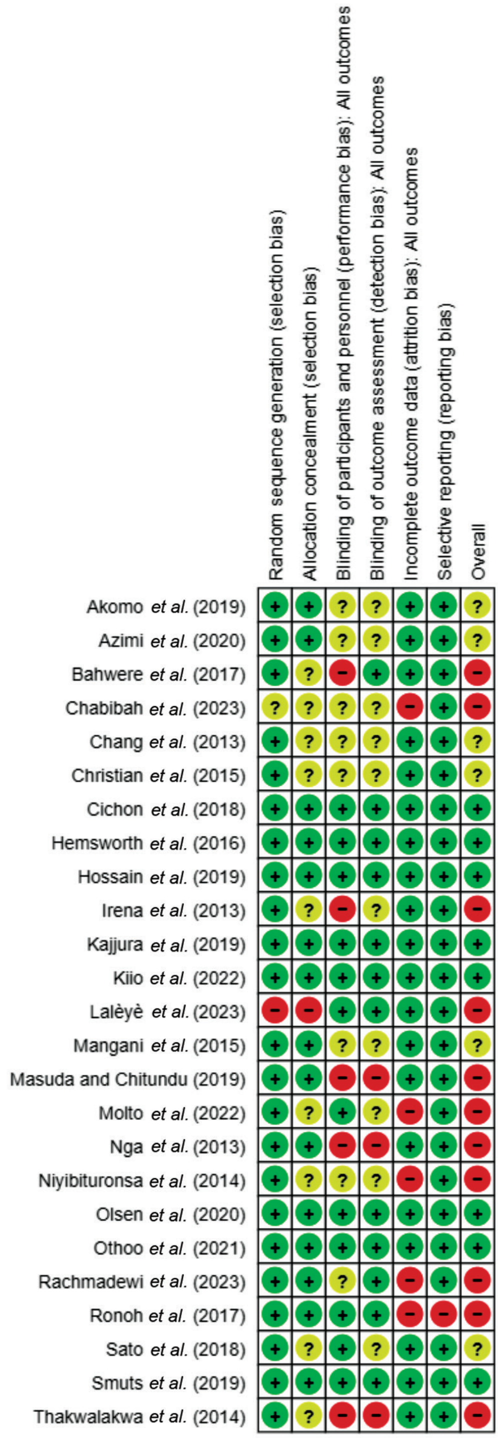

Figure 2: The summary of the risk of bias

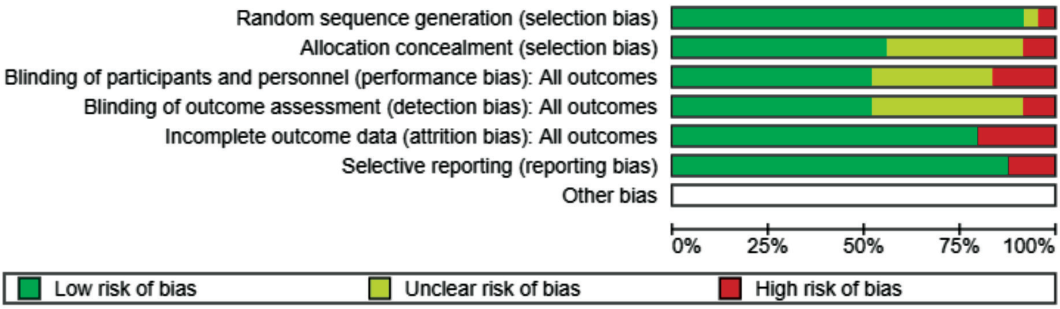

Figure 3: The summary of the risk of bias in the percentage

Further studies by Mangani *et al*. (2015) and Christian *et al*. (2015) observed changes in the LAZ of stunted children, who received soy-based Lipid-based Nutrition Supplements (LNS) of -0.12 and soy-wheat-based RUSF of 0.10, respectively. In Luapala, intervention on stunted and underweight children using soy-corn porridge (13.5% protein per 100 g) for 12 0.70 (± 0.500) cm after four weeks of intervention. This led to increases in WAZ, HAZ, and WHZ months, resulting in an average height growth of 10.6 cm and a weight gain of 2 kg (Masuda & Chitundu, 2019).

Moreover, several studies examined weight gain through soy-based food interventions, including Niyibituronsa *et al*. (2014), who reported weight gains of 0.90 (± 0.900) kg and 0.30 (± 0.200) kg in malnourished children given soy milk and soy soup (250 ml or 125 kcal per day) for three months. On the other hand, (Ronoh *et al*., 2017) established that children categorised as stunted, wasted, and underweight in Western Kenya, who were given 100 g of soy-corn fortified porridge for six months gained an average weight of 1.77 kg.

In Uganda, a study found that malnourished children aged 6 to 18, who received soy-based porridge (control) and malt-supplemented porridge (treatment) for three months showed height increases of 0.99 ± 0.417 and 1.09 ± 0.454 cm and weight gains of 2.99 ± 0.107 and 2.94 ± 0.111 cm, respectively (Kajjura *et al*., 2019). Meanwhile, Hossain *et al*. (2020) reported that acutely malnourished children in Dhaka, Bangladesh, who received soy-based Ready-to-Use Therapeutic Foods (RUTF) (14.5% protein per 100 g) for four months gained 3.90 (± 3.200) kg in weight. Additionally, a study by Chabibah *et al*. (2023) providing intervention to children in Pekalongan, Indonesia, using 100 cc of soy milk fortified with moringa leaves resulted in weight gains of 8.90 (± 4.300) g/kg/day.

Chang *et al*. (2013) conducted a study in the Republic of Malawi and found that children with acute malnutrition, who were given soy-based RUSF (92 g) for 12 weeks showed improved nutritional status marked by increases in WHZ z-scores and MUAC. Lalèyè *et al*. (2023) also assessed that moderately and acutely malnourished children given soy-corn porridge (15% protein per 100 g) for 12 days gained an average weight of 35.45 g/day per child. A study in Bogor, Indonesia, found that acutely malnourished children, who received soy-based RUTF (SOY) for eight weeks gained > 2 g/kg body weight/day compared to other RUTFs ($p > 0.050$).

However, the *p*-value of $p > 0.050$ reported by Rachmadewi *et al*. (2023) indicates that the differences in anthropometric outcomes were not statistically significant, suggesting that the intervention did not significantly impact the growth parameters measured. Similarly, a study by Smuts *et al*. (2019) in Matlosana, South Africa, providing Small-Quantity Lipid-based Nutrition Supplements (SQ LNS) containing soy and milk protein to infants for 26 weeks did not significantly impact WAZ z-scores.

Effect of RUSFs on Nutritional Status

In addition to the significant benefits of increasing weight and height growth in children suffering from stunting or acute malnutrition, these studies also found that soy-based food interventions can provide additional nutrition to support the growth and development of children. Akomo *et al*. (2019) also reported in their study in the Republic of Malawi that severely acutely malnourished children given soy-corn-sorghum-based RUTF (16% to 18% protein per 100 g) for three weeks demonstrated a reduction in anaemia prevalence and improved Body Iron Stores (BIS). Irena *et al*. (2015) stated that in Zambia, using 200 g of soy-corn-sorghum-based RUTF (8.5% protein per 100 g) for six months in acutely malnourished children resulted in a good recovery rate of up to 53.3% with Intention, To-Treat (ITT) analysis.

Another study in the Republic of Malawi investigated the impact of providing 71 g of corn-soy-based food with 10.4% protein per 100 g (284 kcal) to underweight children for nine weeks. The results showed effectiveness in increasing energy and protein intake as well as minerals such as zinc, calcium, iron, and vitamin C (Thakwalakwa *et al*., 2015). Hemsworth *et al*. (2016) in the Republic of Malawi also mentioned that stunted children receiving 10 to 40 g of soy-based LNS (9% protein per 100 g) daily for 13 months showed increased energy and protein intake.

On the other hand, Bahwere *et al*. (2017) conducted an intervention on acutely malnourished children in the Republic of Malawi using soy-corn-sorghum-based RUTF for 90 days. It establishes recovery rates and increases haemoglobin and iron levels, making it effective for anaemia treatment. In Uganda, malnourished children aged 6 to 18 in Uganda who received soy-based porridge (control) and malt-supplemented porridge (treatment) for three months showed increases in haemoglobin levels by 0.48 ± 0.135 and 1.17 ± 0.127 g/dL, respectively (Kajjura *et al*., 2019). Another study by Cichon *et al*. (2018) reported that acutely malnourished children in Burkina Faso, who received soy-based LNS or Corn-Soy-Blend (CSB) (500 kcal/day) for 12 months showed increases in haemoglobin and iron levels, although anaemia prevalence remained high.

Meanwhile, Sato *et al*. (2018) discovered that acutely malnourished children aged 24 to 59 months in the Republic of Malawi who were given locally produced soy-based RUTF for three months showed good plasma essential amino acid levels, comparable to those from standard RUTF intervention [17.8% (1.6, 34.1) and 13.6% (-2.8, 29.9)]. Othoo *et al*. (2021) in Ndhiwa, Kenya, studied the impact of 200 ml soy-corn-based porridge fortified with spirulina given to children for six months on anaemia recovery and found that the recovery was faster compared to using porridge with placebo flour (100% corn). Another study in Thika, Kenya, investigated the relationship of providing 63.75 g of CSB porridge (237.7 kcal with 6.9 g of protein) enriched with micronutrient powder to moderately acutely malnourished children for six months. Consequently, it discovered a significant increase in serum zinc concentration by 18.70 ± 2.1 μg/dL (Kiio *et al*., 2022).

Acceptability of RUSFs

Several studies have conducted trials to test the acceptance of soy-based food products. For instance, Nga *et al*. (2013) discovered a good acceptance of the products, indicated by more than 75% of the offered food being consumed within one hour (meal acceptance) and over 75% of the offered food being consumed for more than 75% of the trial days (overall acceptance). Similarly, Lalèyè *et al*. (2023) reported that participants generally appreciated the soy-corn porridge, with 97% liking it very much, 93% appreciating its consistency, 96% liking its colour, and 81% enjoying its taste. No participants disliked or were neutral towards the porridge and no signs of allergies or rejection were observed. Furthermore, the study by Rachmadewi *et al*. (2023) revealed that products with thinner or less viscous textures were less preferred and accepted by older toddlers and preschool-aged children between 24 and 59 months old. This suggests that factors such as age and product texture play crucial roles in the acceptance levels among children. Therefore, in developing food products for specific age groups, it is essential to consider children's preferences and tolerance regarding consistency and texture to ensure maximum acceptance.

Other Findings

In addition to the previously mentioned analyses, some studies explore the relationship between nutritional interventions and children's cognitive abilities such as motor skills and language development. For example, Olsen *et al*. (2020) established that providing soy isolate-based porridge to acutely malnourished children for 12 and 24 months could increase language z-scores by 0.07 (95% CI: -0.01, 0.15), although this was not statistically significant. The study also found minimal impact on gross and fine motor skill z-scores (-0.01 (95% CI: -0.09 to 0.07) and 0.01 (95% CI: -0.08 to 0.09), respectively. Smuts *et al*. (2019) demonstrated that the median locomotor score increased significantly by 2.05 points (95% CI: 0.72, 3.38; $p = 0.003$). This indicates a 25% improvement compared to the control group over the six months intervention.

Discussion

Soy-based Food Interventions: Practicality and Efficacy

The objective of significantly decreasing children with growth deficits has become a focal point, highlighted by the World Health Assembly's inaugural global nutrition target: Achieving a 40% reduction by 2025 in the number of children under five years old, who experience growth deficits (WHO, 2014). Therefore, there is a pressing need to identify and implement effective food-based interventions that can mitigate the worsening condition of children already affected by growth deficits and prevent it in young children (Kureishy *et al*., 2017). The high cost of milk-based RUF challenges its widespread use, especially in LMICs. Introducing a more affordable alternative like soy-RUF, which uses soy protein could have significant implications if it proves equally effective in treating stunting and malnutrition (Hossain *et al*., 2020).

Several studies have investigated the impact of soy protein-based RUFs on stunted and malnourished children in LMICs, providing valuable insights into their effectiveness. The development of RUFs was predominantly conducted in two continents: Africa (including Malawi, Zambia, Rwanda, Kenya, Burkina Faso, Uganda, South Africa, and the Benin Republic) and Asia (Vietnam, Bangladesh, Iran, and Cambodia). Consequently, the food sources utilised in the formulations were selected based on the respective study locations. In Africa, the ingredients commonly include sorghum, maise, peanuts, malt, and animal-derived sources while in Asia, the formulations typically combined with mungbean, peanuts, moringa, and animal-derived sources, along with omega-3 and omega-6 sources.

The findings from the reviewed studies indicate that soy-based food interventions can be a cost-effective and nutritionally valuable alternative to traditional milk-based RUFs (Fetriyuna *et al*., 2023), especially in LMICs. Soy-based food products have several advantages that make them suitable for nutritional interventions in these regions. Firstly, soy protein is a high-quality protein source that contains all essential amino acids necessary for human growth and development (Qin *et al*., 2022). This makes soy-based products an excellent alternative to animal-derived proteins, typically more expensive and less accessible in many LMICs (Drewnowski, 2024).

Anthropometric and Nutritional Improvements

Soy protein food-based interventions have improved various aspects of child development in those aged six to 59 months. These improvements include better anthropometric measurements, nutritional status, cognitive function, and psychomotor development. Other studies also have shown positive changes in children's weights, heights, and overall body measurements after using these interventions. These findings suggest that plant-based products might significantly fight malnutrition and stunting (Mamun *et al*., 2023). The nutritional benefits of soy-based food products extend beyond their protein content. Soybeans are rich in essential fatty acids, vitamins (such as B vitamins), and minerals (including iron, calcium, and magnesium) (Messina, 2016). Fortified soy-based foods can further enhance these nutritional benefits by adding additional vitamins and minerals as potential catch-up growth in stunting children (Endrinikapoulos *et al*., 2023).

The high protein content of soy and fortification with additional ingredients such as mung beans, wheat, and moringa leaves contributed positively to the intervention outcomes. Numerous studies have demonstrated significant improvements in weight and height among children receiving plant-based interventions. For instance, Azimi *et al*. (2020) reported that children with mild to moderate malnutrition, who received soy-based RUFs experienced considerable weight gain and BMI increases compared to those on a normal diet.

Similarly, Nga *et al*. (2013) discovered that children with severe acute malnutrition in Vietnam showed significant weight and height gains after consuming soy and mung bean-based RUTFs. These interventions enhance anthropometric measurements and improve overall nutritional status, including better z-scores for WAZ, HAZ, and WHZ. Improvements in MUAC have also been noted. Such results are critical in addressing both the immediate and long-term consequences of malnutrition and stunting, which include impaired physical growth, weakened immunity, and reduced cognitive development (Soliman *et al*., 2021). An increase in the anthropometric measures and the nutritional status demonstrates the ability of soy-based interventions to meet the requirement of a child with growth deficits and significantly impact their health in the future.

Cognitive and Psychomotor Development

Besides the physiological changes, studies conducted on soy-based interventions and the effects on cognitive and motorically of the children were done but with limited studies. Olsen *et al*. (2020) noted potential benefits in language development among children, who received soy-based interventions, though these findings were statistically insignificant. Nonetheless, the study indicated that soy-based foods might positively affect cognitive development to some extent. However, these foods were determined to have little effect on children's motor skills. Concerning these outcomes, the duration and frequency of the interventions, as well as overall health conditions and educational support could influence the outcomes. Hence, more research needs to be conducted on these findings to understand these effects fully and establish concrete conclusions.

Acceptance

Their acceptance is crucial for soy-based food products if they have to be used in nutritional programs successfully. Several showed high acceptance levels, the children took large quantities of the given foods, and gave positive attributes of taste, texture, and colour (Nga *et al*., 2013; Lalèyè *et al*., 2023). Based on the effect of the palatability and texture of the product, it is recommended that these variables be modified according to the age factors so that the product can be fully accepted and effective (Rachmadewi *et al*., 2023). Other studies have also shown that soy products can be combined with other foods to enhance the end product's nutritional value and sensory qualities (Cai *et al*., 2021). However, one potential drawback of soy-based products is the beany taste of soy, which is not always desirable. Acceptance may be a problem, particularly where the population has no earlier experience with soy foods (Olías *et al*., 2023). Therefore, strategies like thermal processing, fermentation, or the addition of masking flavours may help reduce this off-flavour and improve palatability (Cai *et al*., 2021).

Sustainability and Local Context

Meanwhile, the efficacy of soy-based interventions is evident, and their sustainability must also be considered. Factors such as the availability of raw materials, local utilisation, and cultural food preferences play a significant role in successfully implementing these interventions (Fetriyuna *et al*., 2021). The use of locally available ingredients, as seen in the formulations of the reviewed studies combining soy with sorghum, maise, mung beans, and other local crops enhances the feasibility and acceptance of these products in different regions. Moreover, sustainability in soy-based interventions also involves adapting production technologies to local contexts.

Simple processing methods such as sun drying and roasting, which are feasible at the household or community level, ensure that production remains cost-effective and manageable (Fetriyuna *et al*., 2023). Proper implementation of these techniques is crucial to maintaining product quality, including nutritional content and sensory attributes. Meanwhile, another opinion suggests that donor-driven RUSF programs, initially overshadowing self-sustaining family nutrition efforts, have shown only temporary success in preventing stunting and malnutrition, highlighting their lack of long-term sustainability (Greiner, 2014). Moreover, collaboration with local communities and stakeholders will be crucial in developing sustainable and culturally acceptable interventions that effectively address child malnutrition (Ghodsi *et al*., 2021).

Policy Implications and Recommendations

According to the answers to the research questions of the current review, soy-based RUFs are suggested to be a feasible approach to addressing issues of children with growth deficits in LMICs. Ideally, policymakers should seek ways to apply these findings to policy practice and soy-based RUFs can be included in the computation of nutrition programs for areas that are always reported to have high incidences of malnutrition among children. This could involve providing subsidies or other incentives to increase the accessibility and affordability of these nutrient-dense foods.

In addition, the review outcomes indicate that these soy-based RUFs should be culturally adapted to make them even more acceptable within local communities. Hence, policymakers should work closely with local stakeholders, including community leaders and healthcare providers. This ensures that the implementation of soy-based RUF programs is tailored to the unique cultural context.

In terms of future research priorities, long-term studies are needed to assess the sustainability of soy-based RUF interventions over time. It will be important to evaluate whether the observed improvements in nutritional status can be maintained and whether these interventions have broader positive impacts on child development, health, and well-being. Furthermore, research should examine the cost of these locally sourced solutions based on soy protein because this will probably inform the resource-constrained LMICs.

Thus, by aligning the presented policy recommendations and research priorities, the policymakers and researchers will be able to guarantee both the comprehensible and sustainable usage of soy-based RUFs to address the persistent challenge of children with growth deficits that remain acute in LMICs, specifically aligning with regional food systems and cultural preferences.

The findings of the present study on soy-based RUFs in LMICs are consistent with the existing literature in several respects but also highlight notable differences and gaps in knowledge. Our study demonstrated the potential of soy-based RUFs to prevent and even reverse growth deficits among under fives and improve anthropometric outcomes and nutrition status among this group, which can be seen in Figure 4. However, while some studies

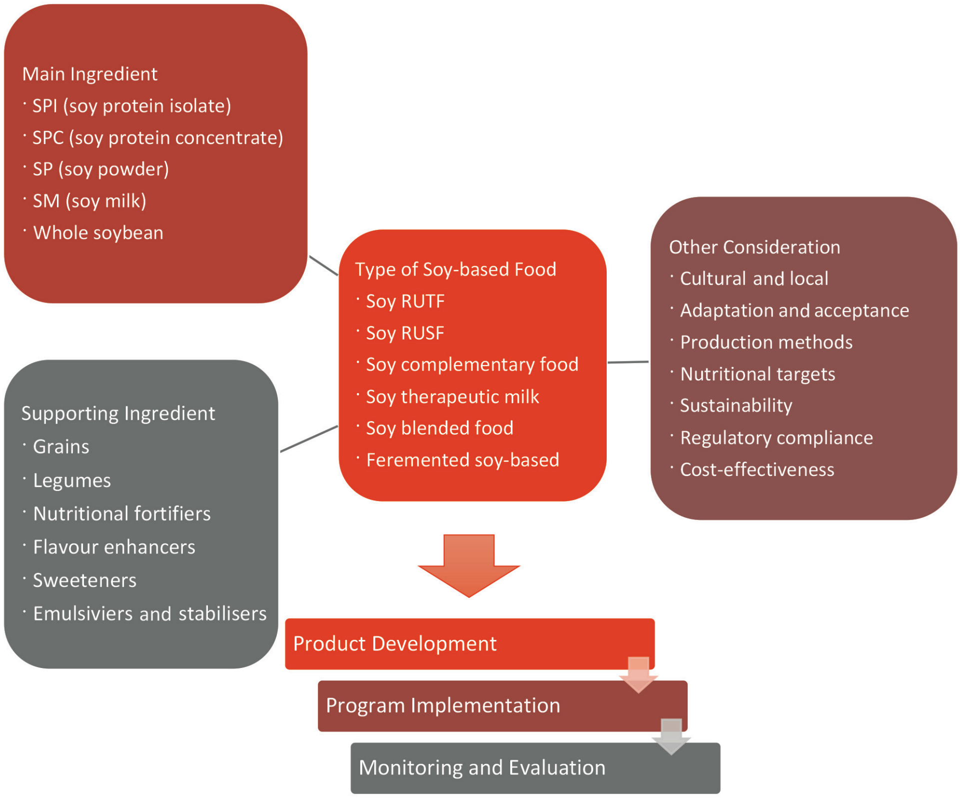

Figure 4: The framework of soy-based food intervention

have found significant effects, others have reported more modest or insignificant findings. Differences across studies may arise due to varying study designs, intervention durations, characteristics of the study samples as well as contextual factors such as socioeconomic status and dietary habits (Mattes *et al*., 2022).

Therefore, future research should address these limitations and better understand the mechanisms behind soy-based RUFs' effects on health outcomes in LMICs. By doing so, we can advance our understanding of effective strategies to combat stunting and malnutrition, address immediate health concerns, and promote sustainable development in these countries. Future research is needed to understand better which components of these interventions are most effective and can be easily delivered at large scale in different cultural settings. In addition, more is required to clarify the dose-response relationships between the amount of coverage of a specific intervention needed to produce an effect on linear growth and when the intervention should be delivered for optimal effects (i.e., during pregnancy, early infancy, or both).

Conclusions

In conclusion, soy can be considered an alternative protein due to its relatively low price, nutritional benefits, and local accessibility, especially for the needs of LMICs. Intervention of soy-based RUFs can potentially prevent the worsening of children with growth deficits and even improve their anthropometric outcomes and nutritional status in LMICs. However, this article has a limited discussion on the potential challenges and barriers to implementing such interventions, including cultural acceptance, supply chain logistics, and long-term sustainability. Hence, future studies should focus on identifying the most effective components of these interventions that can be easily scaled up and delivered across diverse cultural settings. It is also necessary to understand the dose-response relationships, i.e., how much or what coverage of a given intervention is required to achieve a meaningful impact on linear growth and the timing for delivery of interventions, i.e., during pregnancy, early infancy, or both, for maximum impact.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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