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The use of linear programming approach in diet optimization among children under five: a scoping review

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Abstract

Background Adequate nutrition is crucial for optimal child growth and development, especially for children under five. Over the years, the linear programming (LP) approach has been used to develop food-based recommendations (FBRs) for children under five.

Objective This scoping review aims to (i) summarize the use of LP in diet optimization to improve nutrient adequacy, (ii) evaluate nutrient requirements by using modelling techniques when the use of local foods is optimized, and (iii) identify and compare the problem nutrient(s).

Methods This scoping review was performed by searching PubMed and Wiley databases from 2012 to 2025, and also screened the reference lists of included publications to identify potentially eligible articles. Forward and backward citation searches were also performed to supplement the structured searches in the databases.

Results Fourteen studies were included after a systematic literature search. The objective functions and the final set of FBRs of the included studies were summarized. Moreover, the nutrient intakes in the optimized diets and the problem nutrients of the included studies were compared and discussed. When optimizing diets using the LP approach, most of the nutrient requirements can be achieved, except for iron and zinc and, in some studies, thiamine, niacin, folate, and calcium. Iron was identified as the problem nutrient in all studies involving infants aged 6 to 11 months old, followed by calcium and zinc. In children aged 12 to 23 months, iron and calcium were identified as the problem nutrients in almost all studies, followed by zinc and folate. In children aged 1 to 3 years, fat, calcium, iron, and zinc were recognized as the absolute problem nutrients, while fat, calcium, and zinc were the absolute problem nutrients for children aged 4 to 5 years. Findings on dietary inadequacy of nutrient intakes were remarkably consistent across studies conducted in different geographic and socioeconomic settings.

Conclusions Modeled diets involving local foods are inadequate to meet the requirements for certain micronutrients, particularly iron and zinc. Cost-effective strategies are required to improve the dietary adequacy of young children.

Keywords Linear programming, Diet optimization, Undernutrition, Young children, Dietary intake

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Introduction

Malnutrition remains a critical public health concern, particularly among young children under five, who require adequate nutrition to support rapid growth and development [1]. Providing a nutritionally balanced diet during this crucial period is essential for preventing undernutrition and mitigating long-term adverse health outcomes in adulthood [2]. Although global efforts have led to a decline in undernutrition among children under five, progress has been slower than expected. The prevalence of underweight [weight-for-age z-score (WAZ) more than two standard deviations (SDs) below the median of the WHO Child Growth Standards] decreased from 12.9% (87 million) in 2019 to 12.6% (85 million) in 2020, while wasting [weight-for-height z-score (WHZ) more than two SDs below the median of the WHO Child Growth Standards] decreased from 6.9% (47 million) to 6.8% (45 million) between 2019 and 2022. However, stunting [height-for-age z-score (HAZ) more than two SDs below the median of the WHO Child Growth Standards] increased from 21.3% (144 million) in 2019 to 22.3% (148 million) in 2022 [3–5]. These trends highlight the ongoing challenges in addressing childhood undernutrition and its far-reaching consequences, which include increased the risk of mortality and morbidity, impaired cognitive and academic performance, reduced economic productivity and earnings, and increase future risk of being overweight and subsequently NCDs [6, 7]. Moreover, undernutrition is associated with poor child development in several domains, including behavioral, cognitive, language and sensory-motor skills [6, 8, 9].

The use of locally available foods has been highlighted in the WHO/UNICEF Global Strategy for Infant and Young Children Feeding as one of the important strategies to promote nutrition for optimal growth and development of young children [10]. The ideas of diversity and simplicity, which are related to the perception of healthy eating, can be used to categorize a healthy and balanced diet [11]. A healthy diet can be achieved by consuming foods that contain the recommended amounts of macronutrients and micronutrients in alignment with dietary guidelines [12]. Dietary guidelines are designed to promote health and prevent diet-related chronic diseases [13, 14]. However, the process of formulating dietary guidelines is complex and time-consuming, involving expert consultation and consideration of multiple factors such as nutritional problems, food patterns, food availability, and food affordability [14]. Moreover, traditional dietary assessment methods often fail to identify practical and sustainable solutions for meeting nutrient requirements. To address these challenges, linear programming (LP) has been developed as a tool to formulate population-specific dietary recommendations while identifying nutrient gaps that cannot be met using locally available foods alone [15].

Linear programming has become increasingly popular in recent years for planning and optimizing healthy diets [1]. The concept of mathematical diet optimization began in the 1940s when Georges Stigler used the 'diet problem' as an example to illustrate how a complex problem could be transformed into a mathematical model [16]. The decision variables, constraints, and objective function are the parameters of a mathematical optimization problem. In mathematical optimization, an optimization model seeks to satisfy a set of equalities or inequalities, known as constraints, by identifying the unique combination of values for decision variables that yields the best outcome for a single objective function [1]. The objective function is the real-valued function whose value is to be either minimized or maximized, subject to the constraints. In the context of nutrition, the goal of diet optimization is to identify a unique combination of foods that meets dietary recommendations and/or maximum amounts of foods, food groups, and/or other constraints (such as energy and nutrient constraints) while minimizing or maximizing an objective (such as total diet cost, energy content, or total deviation from the observed diet).

The application of LP in nutrition dates back several decades, with tools such as WHO's Optifood [17] and WFP's NutVal [18] being used to design nutritionally adequate, cost-effective, and context-specific diets. These tools assist in optimizing food combinations that maximize nutrient intake within realistic dietary constraints, contributing to sustainable diet formulation. In the context of infant and young child feeding, LP has been applied to refine complementary feeding recommendations, as demonstrated in the WHO technical paper by Dewey and colleagues [19]. Their study highlights how LP can systematically assess food-based approaches to improve dietary adequacy and bridge nutrient gaps using locally available and affordable foods, thereby providing a practical framework for developing evidence-based nutrition interventions [19].

According to Anderson and Earle [20], LP can be used to determine the optimal allocation of a limited supply of food materials, subject to certain constraints, to optimize a specific objective function. Therefore, LP is often used to select dietary components to meet specific nutritional requirements at a minimum cost [20]. It can be a useful approach for identifying nutrient inadequacies [21], which can provide additional information for nutrition program planning and advocacy. Moreover, LP can be used to formulate dietary recommendations at the lowest possible cost while ensuring that they meet the requirements for all macronutrients and micronutrients set by dietary guidelines established by health professionals

[22]. Reham et al. [23] suggested that LP could be applied to diet-related problems by developing dietary recommendations that contained all the optimal foods, cost, and quality of a diet.

Despite the growing application of LP in diet optimization, no scoping review has examined its role in improving nutrient adequacy among children under five. This gap highlights the need for a comprehensive synthesis of the existing evidence to better understand how LP can be used to improve dietary recommendations for young children. Therefore, this scoping review aims to (i) summarize the use of LP in diet optimization to improve nutrient adequacy (including the objective function(s) and the final set of locally appropriate food-based recommendations (FBRs) that improve the nutrient adequacy of the target population), (ii) evaluate whether the nutrient requirements can be achieved using modeling techniques when the use of local foods is optimized, and (iii) identify and compare the problem nutrient(s) across studies. The findings of this scoping review can provide useful information for policy makers and health professionals in establishing the role of diet optimization models in improving nutrient adequacy as a potential health promotion tool in young children.

Methods

The methodology used in this scoping review followed the framework originally proposed by Arksey and O'Malley [24] and later refined by Levac et al. [25] and Colquhoun et al. [26]. The review question was guided by the Population, Concept and Context (PCC) strategy: What is known about the use of LP in diet optimization to improve nutrient adequacy in children under five years of age based on literature? The search adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes extension for Scoping Reviews (PRISMA-ScR) checklist [27] to ensure a robust and replicable process. Ethical approval was not required for this study, as it is a review paper.

Search strategy

A preliminary scoping search was conducted to determine the feasibility of this review. Two reviewers (YXM and WKHM) independently verified the search strategy after it was developed. An extensive literature search was conducted using PubMed and Wiley, and the reference lists of included publications were scanned for potentially eligible articles. Forward and backward citation searches were also performed to supplement the structured searches in the databases.

The search keywords used for this review included the following:

1. linear programming OR mathematical optimization OR diet modeling (Note: The words "optimization" and "modeling" were also tested with the British spellings "optimisation" and "modelling", respectively).

AND

2. diet optimization OR diet planning OR diet intake OR dietary intake OR food intake OR food consumption OR food choice OR food selection OR nutrient intake OR dietary guideline OR food-based recommendation OR food-based dietary recommendation OR nutritional requirement (Note: The word "optimization" was also tested with the British spelling "optimisation").

Eligibility criteria

The inclusion criteria for this review were as follows: 1) the use of mathematical optimization techniques; 2) application of a whole-diet approach; 3) focused on human participants only; and 4) involved participants aged less than 5 years old. The exclusion criteria were as follows: 1) studies involving participants with any chronic disease (such as diabetes, asthma, cerebral palsy, epilepsy, congenital metabolic disorders) or disability; 2) studies involving food substitution for clinical purposes; 3) studies of vegetarian diets; and 4) review articles.

Selection of included publications

Publications that met the following selection criteria were included in this review: 1) full-text articles published or accepted from 2012 to 2025; 2) exclusion of non-peer-reviewed articles, protocols, reports, abstracts, conference proceedings, and policy briefs; and 3) articles written in English. All articles identified in the database search were screened for eligibility by reviewing the title and abstract of each article listed. The full text of potentially eligible articles was retrieved for further screening of their suitability based on the review question and inclusion criteria. Figure 1 illustrates the flowchart of the screening process used to identify eligible articles for a comprehensive review of the application of LP in diet optimization. Data were charted, and the results were summarized based on a review of the full text of the identified articles.

Data extraction

First, two independent reviewers (YXM and WKHM) conducted a title and abstract review based on a broad inclusion criterion of diet optimization by using LP. Papers identified by either or both reviewers proceeded

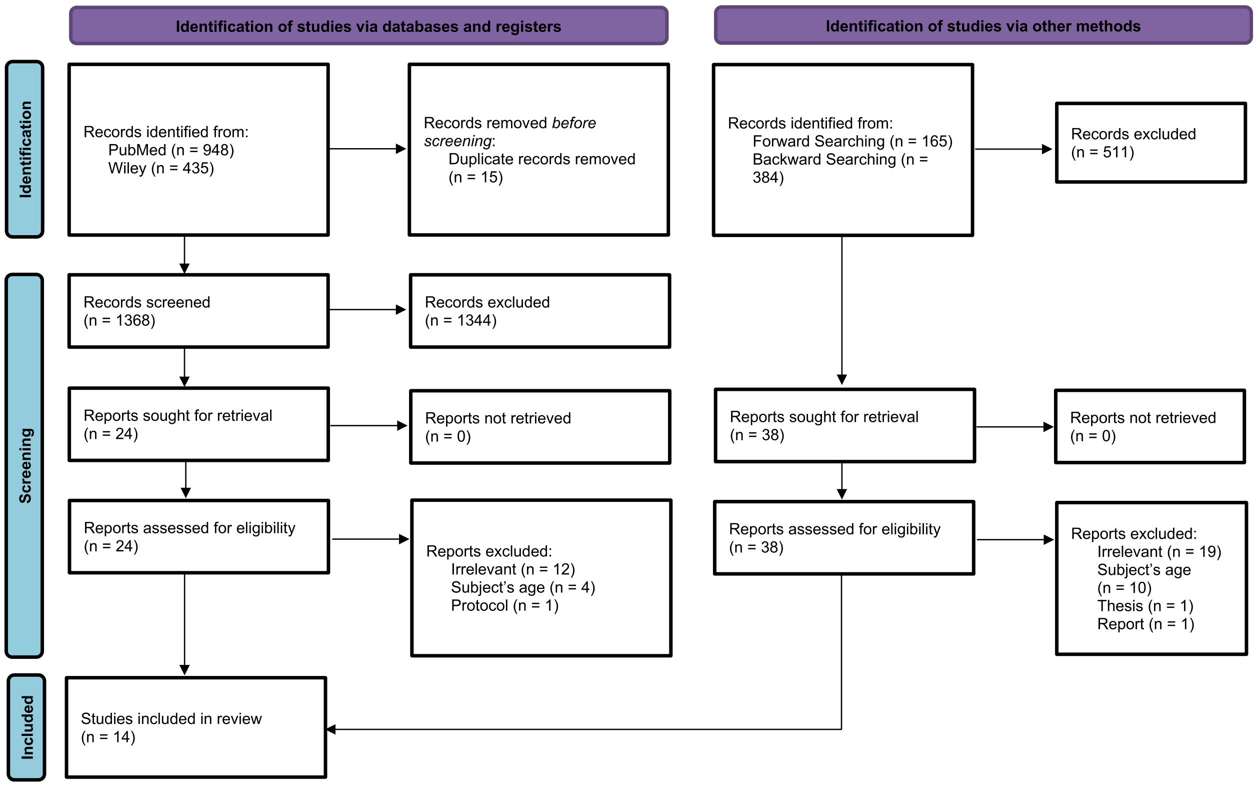

Fig. 1 PRISMA flow diagram for the scoping review process

to the next phase. In the second phase, the same two reviewers (YXM and WKHM) independently screened the full-text articles against the above eligibility criteria while documenting the reasons for exclusion and rechecked by WYG and PYL to ensure fair results of the paper search and refinement. Key characteristics of all included studies were then tabulated using an Excel spreadsheet. These extracted data included details of study characteristics (such as author(s), year of publication, journal, study location, study design, and software used), target population characteristics (such as sample size, age and gender), interest of study (such as level of study and objective function), and study outcomes (such as food-based recommendations). The results were then presented as a data map in tabular form showing study characteristics, target population characteristics, interest in the study, and study outcomes.

Results

A total of 1383 records were identified after the systematic search using PubMed ($n=948$) and Wiley ($n=435$). Duplicate records ($n=15$) and unrelated articles ($n=1344$) were removed. On the other hand, 549 records were added for review by scanning secondary references (forward and backward citation search). A total of 62 articles were assessed for eligibility. After excluding articles for reasons such as irrelevant topic ($n=31$), subject's age ($n=14$), protocol ($n=1$), thesis ($n=1$), and report ($n=1$), 14 articles were selected for further review, as shown in Fig. 1.

Table 1 shows the characteristics of the included studies. Nine of the 14 studies reported total dietary intakes, that is, intake from breastmilk consumption and complementary foods [17, 22, 28–30, 33, 34, 38, 39]. Of these nine studies, three reported the median and interquartile range [28, 33, 39], while one reported only the median [30]. Three studies reported the absolute dietary intake from daily diets as the median and interquartile range [32, 36] or median only [35]. Dietary intake was not reported in two studies [31, 37]. Ten studies that involved breastfeeding, infants and children were 100% breastfed in seven studies [17, 28–30, 37–39], followed by 92.7% [34], 91.4% [33], and 78.7% [22]. All 14 studies reported findings for at least one of the following age subgroups: 6 to 8 months ($n=7$) [17, 28–30, 33, 34, 37], 6 to 11 months ($n=1$) [38], 9 to 11 months ($n=7$) [17, 28–30, 33, 34, 37], 12 to 23 months ($n=9$) [22, 28–31, 33, 34, 37, 39], 1 to 3 years ($n=1$) [35], 4 to 5 years ($n=1$) [35], and 4 to 6 years ($n=2$) [32, 36]. Ten studies were from Africa

Table 1 Characteristics of the included studies

No	Author (Year)	Study Location	Study Design	Total Sample	Age	Dietary Intake Methods	Software Used
1	Skau et al. (2014) [17]	Cambodia	Cross-sectional	78 infants	6 to 8 months old ($n = 35$) 9 to 11 months old ($n = 43$)	Single 24-h dietary recall	Optifood software
2	Ferguson et al. (2015) [28]	Kenya	Cross-sectional	335 infants and children	6 to 8 months old ($n = 94$) 9 to 11 months old ($n = 65$) 12 to 23 months old ($n = 176$)	Four-pass 24-h dietary recall	Optifood software
3	Hlaing et al. (2016) [22]	Myanmar	Cross-sectional	106 children	12 to 23 months old	12-h weighted dietary record 12- and 24-h dietary recalls 5-d food record	Optifood software
4	Vossenaar et al. (2016) [29]	Northern Kenya	Cross-sectional	882 infants and children	6 to 8 months old ($n = 228$) 9 to 11 months old ($n = 314$) 12 to 23 months old ($n = 340$)	Multiple-pass 24-h dietary recall	Optifood software
5	Raymond et al. (2017) [30]	Tanzania	Cross-sectional	400 infants and children	6 to 8 months old ($n = 100$) 9 to 11 months old ($n = 100$) 12 to 23 months old ($n = 200$)	Weighed dietary record 24-h dietary recall 7-d food record	Microsoft Excel 2013 and linear program solver version (LiPS)
6	Tharrey et al. (2017) [31]	Colombia	Secondary data	72 children	12 to 23 months old	24-h dietary recall	Optifood software
7	Kujinga et al. (2018) [32]	West Kenya	Cross-sectional	60 children	4 to 6 years old	Multiple-pass 24-h dietary recall	Optifood software
8	de Jager et al. (2019) [33]	Northern Ghana	Cross-sectional	337 infants and children	6 to 8 months old ($n = 97$) 9 to 11 months old ($n = 97$) 12 to 23 months old ($n = 143$)	Multiple-pass 24-h dietary recall	Optifood software
9	Samuel et al. (2019) [34]	Ethiopia	Secondary data	2498 infants and children	6 to 8 months old ($n = 497$) 9 to 11 months old ($n = 464$) 12 to 23 months old ($n = 1537$)	NR	Optifood software
10	Chileshe et al. (2020) [35]	Zambia	Cross-sectional	221 children	1 to 3 years old ($n = 156$) 4 to 5 years old ($n = 65$)	Multiple-pass 24-h dietary recall	Optifood software
11	Borgonjen-van den Berg et al. (2021) [36]	West Kenya	Cross-sectional	62 children	4 to 6 years old	Multiple-pass 24-h dietary recall	Optifood software
12	Mejos et al. (2021) [37]	Philippines	Cross-sectional	297 infants and children	6 to 8 months old ($n = 58$) 9 to 11 months old ($n = 100$) 12 to 23 months old ($n = 139$)	Multiple-pass 24-h dietary recall 7-d food consumption frequency	Optifood software
13	Sayed & Schönfeldt (2022) [38]	Africa	Cross-sectional	134 infants	6 to 11 months old	NR	Optifood software
14	Kimere et al. (2022) [39]	Eastern Uganda	Cross-sectional	114 children	12 to 23 months old	1-d weighted food record	Optifood software

NR Not Reported

[28–30, 32–36, 38, 39], three studies were from Asia [17, 22, 37], and one from America [31]. Twelve studies [17, 22, 28–30, 32, 33, 35–39] were cross-sectional, while two studies [31, 34] obtained data from a randomized control trial and national survey, respectively. Half of the studies reported dietary intake from multiple-pass 24-h dietary recalls [28, 29, 32, 33, 35–37], while only three studies reported dietary intake from weighed food records [22, 30, 39]. Table 1 summarizes the characteristics of the 14 included studies.

Objective functions

To develop evidence-based FBRs for specific populations, a mathematical approach based on LP analysis was developed–Optifood software. All studies except the study by Raymond et al. [30] used Optifood to develop population-specific FBRs. In Optifood, FBRs can be developed by using three modules with their respective objective functions. The first module is used to check that the model parameters are realistic. Its objective function is to minimize and maximize the energy content to test the model parameters. The second module is used to identify the diet that would meet or come as close as possible to meeting the nutrient needs, within the model parameters, as well as the best possible diet regardless of these parameters. In addition, this module was used to identify problem nutrients and food sources of problem nutrients to develop food-based dietary recommendations. Its objective function is to minimize relative deviations below the nutrient goals to develop draft FBRs. The third module is used to test and compare alternative FBRs, taking into account current dietary patterns, nutrient requirements, and costs. Its objective function is to maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content.

Table 2 summarizes the objective functions and presents the final set of locally appropriate FBRs of the included studies. For the study by Raymond et al. [30], the objective function is to minimize deviations from the population's food subgroup patterns for 11 food subgroups while meeting the required dietary standards. Eight studies [17, 32–38] included two macronutrients, protein and fat, while only four studies [22, 28, 30, 31] included one macronutrient, protein. All studies included at least 11 micronutrients: vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc. Raymond et al. [30] included 9 additional micronutrients, including pantothenic acid, vitamin D, vitamin E, copper, magnesium, manganese, phosphorus, potassium, and sodium, while de Jager et al. [33] included three additional micronutrients, including isoleucine, lysine, and aromatic amino acids.

Nutrient achievement in optimized diets

The optimized, best-case scenario, and worst-case scenario diets for each nutrient of the included studies were expressed as a percentage of the recommendations (recommended nutrient intakes) in Table 3. The findings of the studies were reported and discussed according to age subgroups. The categories of age subgroups have been mentioned elsewhere in this article. Nine studies reported nutrient achievement for at least one of the following combinations: optimized diet, best-case scenario, and worst-case scenario [17, 22, 34, 39], optimized diet and worst-case scenario [28, 35], and best-case and worst-case scenarios [32, 33, 37]. The studies by Borgonjen-van den Berg et al. [36] and Sayed et al. [38] reported the optimized diet and the best-case scenario, while the study by Tharrey et al. [31] reported the optimized diet only. Complete nutrient achievement was not found in the two studies [29, 30]. Nutrient achievement was discussed in the studies that reported optimized diets [17, 22, 28, 31, 34–36, 38, 39].

For infants aged 6 to 8 months, modeled dietary intakes from local foods were adequate in all optimized diets for vitamin A, vitamin B12 and vitamin C, whereas iron and zinc did not achieve 100% in all optimized diets [17, 28, 34]. Remarkably, riboflavin (74%) was found to be inadequate in only one study [17], while both thiamine (127% and 100%) and vitamin B6 (157% and 136%) were found to be adequate in another study [28]. Ferguson et al. [28] showed the lowest number of inadequate nutrient intakes ($n=2$), which was iron and zinc, for Kitui infants. On the contrary, Skau et al. [17] showed the highest number of inadequate nutrient intakes ($n=7$) for Cambodian infants. Samuel et al. [34] found that Tigray infants had two times lesser inadequate nutrient achievement ($n=3$) compared to those from other regions in the study. Protein [17, 34] and fat [34] met the estimated requirements from local foods for infants in all studies reporting data for this age subgroup. For infants aged 6 to 11 months, the findings of the optimized diet identified iron and zinc as the nutrients of concern [38]. The highest achievable %RNI did not reach 100% for iron (56%) and zinc (66%) [38]. Protein (214%) met the estimated requirements from local foods for infants in this age subgroup.

In contrast, for infants aged 9 to 11 months, modeled nutrient intakes from local foods were adequate in all optimized diets for vitamins A, B6, B12, and C, while iron and zinc did not achieve 100% in all optimized diets [17, 28, 34]. The fact that all studies [17, 28, 34] in the age subgroup did not report inadequacy for vitamin B6 seems to indicate that meeting nutrient requirements from local foods may improve with age. Niacin was found to be inadequate only in the Ethiopian study [34]. Ferguson et al. [28] showed the lowest number of inadequate

Table 2 Objective functions and final set of locally appropriate FBRs of the included studies

Author (Year)	Objective Functions	Food-Based Recommendations
Skau et al (2014) [14]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content Five models were developed to test the relevance of fortified foods The models included: Nothing (Baseline), WinFood (WF), WinFood-Lite (WF-L), Corn-Soy-Blend Plus (CSB+), and Corn-Soy-Blend Plus Plus (CSB++) products This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**6 to 8 months old** Breastfeed on demand, fruits three times weekly, vegetables at least once daily, MFE three times daily, and WinFood once daily **9 to 11 months old** Breastfeed on demand, bakery and breakfast cereals once weekly, fruits five times weekly, vegetables twice daily, MFE at least twice daily, and WinFood at least once daily
Ferguson et al. (2015) [28]	Module I: check model parameters and to make decisions about which of the two alternative breast milk serving sizes would be used in the analyses Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 1 macronutrient (protein) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**Kitui**[a] **6 to 11 months old** Breastfeed on demand, millet flour once daily, fortified cereal once daily, DGLV once daily, legumes or MFE once daily, and full fat cows' or goats' milk three times daily, **12 to 23 months old** Breastfeed on demand, millet flour once daily, fortified cereal once daily, DGLV once daily, MFE once daily (small fish three times weekly), legumes twice daily, and full fat cows' or goats' milk three times daily **Vihiga**[a] **6 to 11 months old** Breastfeed on demand, bean flour once daily, fortified cereal three times weekly, DGLV once daily, small fish five times weekly, and full fat cows' or goats' milk twice daily **12 to 23 months old** Breastfeed on demand, legume or bean flour once daily, fortified cereal four times weekly, DGLV twice daily, small fish five times weekly, and full fat cows' or goats' milk three times daily
Hlaing et al (2016) [22]	Module I: check model parameters and to make decisions about which of the two alternative breast milk serving sizes would be used in the analyses Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 1 macronutrient (protein) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**12 to 23 months old** Breastfeed on demand, fortified cereal-based beverages five times weekly, vegetables or fruits once daily (roselle leaves once weekly), animal protein once daily (of which liver once weekly, anchovy once weekly, and eggs twice weekly), and cooked beans and lentils three times weekly

Table 2 (continued)

Author (Year)	Objective Functions	Food-Based Recommendations
Vossenaar et al. (2016) [29]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**Settled Communities[b]** **6 to 8 months old** Potato or green banana once daily, beans once daily and animal milk twice daily **9 to 11 months old** Grains and grain products once daily, potato or green banana twice daily, beans at least once daily, and animal milk twice daily **12 to 23 months old** Grains and grain products once daily, potato or green banana twice daily, beans at least once daily, and animal milk three times daily **Pastoralist Communities[b]** **6 to 8 months old** Grains and grain products once daily, potato or green banana once daily, vegetables once daily, animal milk twice daily, and vitamin A-fortified fats once daily **9 to 11 months old** Grains and grain products once daily, potato or green banana ten times weekly, vegetables once daily, animal milk twice daily, and vitamin A-fortified fats six times weekly **12 to 23 months old** Grains and grain products twice daily, potato or green banana ten times weekly, vegetables twice daily, animal milk three times daily, and vitamin A-fortified fats once daily **Agro-pastoralist Communities[b]** **6 to 8 months old** Potato or green banana once daily, beans six times weekly, and animal milk twelve times weekly **9 to 11 months old** Potato or green banana five times weekly, beans once daily, and animal milk twice daily **12 to 23 months old** Potato or green banana three times weekly, beans once daily, and animal milk seventeen times weekly
Raymond et al. (2017) [30]	To minimize deviations from the population's food subgroup patterns for 11 food subgroups while simultaneously meeting the required dietary standards This study involved 1 macronutrient (protein) and 20 micronutrients (vitamin A, thiamine, riboflavin, niacin, pantothenic acid, vitamin B6, folate, vitamin B12, vitamin C, vitamin D, vitamin E, calcium, iron, zinc, copper, magnesium, manganese, phosphorus, potassium, and sodium	The nutritional goals of iron and vitamin D for infants who aged 6 to 8 months old were not achieved The nutritional goals of iron and vitamin D for infants who aged 9 to 11 months old were not achieved All nutritional goals for children who aged 12 to 23 months old were achieved

Table 2 (continued)

Author (Year)	Objective Functions	Food-Based Recommendations
Tharrey et al. (2017) [31]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 1 macronutrient (protein) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**12 to 23 months old** Vitamin A-rich vegetables twice daily, chicken giblets three times weekly, dairy products twice daily (of which cow's milk once daily), and legumes once daily
Kujinga et al. (2018) [32]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**4 to 6 years old** Whole grain products twice daily, starchy plants once daily, vegetables twice daily (of which vitamin A source once daily and vitamin C source once daily), small whole fish with bones once daily, nuts and seeds four times weekly, and fluid or powdered milk once daily
de Jager et al. (2019) [33]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 12 micronutrients (vitamin A, riboflavin, niacin, folate, vitamin B12, vitamin C, calcium, iron, zinc, isoleucine, lysine, and aromatic amino acids)	**6 to 8 months old (Breastfed)** Breastfeed on demand, soybean flour once daily, vegetables three times daily, nuts or seeds once daily, and beans twice daily, and dairy products once daily **9 to 11 months old (Breastfed)** Breastfeed on demand, whole grains three times daily, fruits once daily, DGLV twice daily, fish three times daily, and beans once daily **12 to 23 months old (Breastfed)** Breastfeed on demand, whole grains once daily, fruits once daily, DGLV twice daily, nuts or seeds three times daily, beans twice daily (of which extra cowpea once daily), and dairy products once daily **12 to 23 months old (Non-Breastfed)** Whole grains once daily, DGLV twice daily, fish once daily, nuts or seeds three times daily, and beans twice daily (of which extra cowpea once daily)

Table 2 (continued)

Author (Year)	Objective Functions	Food-Based Recommendations
Samuel et al. (2019) [34]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**Tigray[c]** **6 to 8 months old** Breastfeed on demand, grains four times weekly, fortified cereal once daily, and dairy products once daily **9 to 11 months old** Breastfeed on demand, grains once daily, vegetables once daily, legumes twice daily and dairy products once daily **12 to 23 months old** Breastfeed on demand, grains twice daily, vegetables three to four times weekly, eggs once daily, legumes twice daily, and dairy products once daily **Amhara[c]** **6 to 8 months old** Breastfeed on demand, fortified cereal once daily, legumes once daily, and dairy products once daily **9 to 11 months old** Breastfeed on demand, grains twice daily, starchy roots once daily, legumes once daily, and dairy products once daily **12 to 23 months old** Breastfeed on demand, grains twice daily, starchy roots once daily, vegetables twice daily, legumes three times daily, and dairy products once daily **Oromia[c]** **6 to 8 months old** Breastfeed on demand, grains once daily, starchy roots once daily, legumes once daily, and dairy products three to four times weekly **9 to 11 months old** Breastfeed on demand, grains twice daily, vegetables twice daily, legumes three to four times weekly, and dairy products three to four times weekly **12 to 23 months old** Breastfeed on demand, grains twice daily, vegetables twice daily, eggs once daily, legumes twice daily, and dairy products three to four times weekly **South Nations, Nationalities and Peoples Region (SNNPR)[c]** **6 to 8 months old** Breastfeed on demand, grains twice daily, legumes three times daily, and dairy products three to four times weekly **9 to 11 months old** Breastfeed on demand, grains five times daily, starchy roots three to four times weekly, DGLV once daily, legumes twice daily, and dairy products three to four times weekly **12 to 23 months old** Breastfeed on demand, grains three times daily, eggs once daily, legumes three times daily, and dairy products once daily

Table 2 (continued)

Author (Year)	Objective Functions	Food-Based Recommendations
Chileshe et al. (2020) [35]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**1 to 3 years old** Grains and grain products once daily; vegetables three times daily; rape leaves once daily; small whole fish with bones two times weekly; cooked beans, lentils and peas three times weekly; nuts, seeds and unsweetened products four times weekly; and Mabisi once daily **4 to 5 years old** Grains and grain products six times weekly; vegetables three times daily; rape leaves once daily; small whole fish with bones two times weekly; cooked beans, lentils and peas three times weekly; nuts, seeds and unsweetened products three times weekly; and Mabisi six times weekly
Borgonjen-van den Berg et al. (2021) [36]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**4 to 6 years old** Grains and grain products three times daily; fruits once daily; vegetables four times daily; meat, fish and eggs once daily; legumes, nuts and seeds four times weekly; dairy products eight times weekly; and added fats once daily;
Mejos et al. (2021) [37]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**6 to 8 months old** Grains and grain products four times weekly, fruits three times weekly, vegetables six times weekly, legumes three times weekly, and liver one time weekly **9 to 11 months old** Grains and grain products six times weekly, fruits four times weekly, vegetables once daily, eggs three times weekly, legumes three times weekly, and liver one time weekly **12 to 23 months old** Fruits once daily, vegetables thirteen times weekly, fish three times weekly, eggs three times weekly, beans three times weekly, liver one time weekly, and fortified beverage one time weekly
Sayed & Schönfeldt (2022) [38]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 2 macronutrients (protein and fat) and 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	The nutritional goals of iron and zinc for infants who aged 6 to 11 months old were not achieved
Kimere et al. (2022) [39]	Module I: minimize and maximize energy content to test model parameters Module II: minimize relative deviations below the nutrient goals to develop draft FBRs Module III: maximize (to identify problem nutrients) or minimize (to test FBRs) the nutrient content This study involved 11 micronutrients (vitamin A, thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin C, calcium, iron, and zinc)	**FBR 1** Sweet potatoes once weekly, fruits twice daily, DGLV four times weekly, legumes twice daily, and milk twice daily **FBR 2** Whole grain cereals twice daily; sweet potatoes once daily; DGLV four times weekly; meat, fish and eggs once daily; and legumes twice daily

FBR Food-Based Recommendations, *DGLV* dark green leafy vegetables, *MFE* meat, fish and eggs

[a] Counties in Kenya

[b] Three main livelihood groups from three food-insecure counties in northern Kenya, namely, settled communities from Isiolo, pastoralist communities from Marsabit, and agro-pastoralist communities from Turkana

[c] The four largest regions in Ethiopia represent different local cultures and child feeding habits and practices

Table 3 The optimized, best-case scenario, and worst-case scenario diets for each nutrient expressed as a percentage of their recommendations (Recommended Nutrient Intakes) in the included studies

	Protein	Fat	Vit A (RE)	Thiamine	Riboflavin	Niacin	Vit B6	Folate (DFE)	Vit B12	Vit C	Calcium	Iron	Zinc
Skau et al. (2014) [17]													
6 to 8 m/o													
Optimized diet	168	NR	121	74	74	86	94	55	183	133	100	22	73
Best-case scenario	170	NR	140	77	75	88	102	60	193	148	107	24	73
Worst-case scenario	127	NR	90	48	59	69	67	41	140	97	93	17	66
9 to 11 m/o													
Optimized diet	178	NR	136	76	73	101	108	62	220	137	114	28	86
Best-case scenario	190	NR	147	77	75	117	136	69	228	143	121	29	88
Worst-case scenario	130	NR	85	52	58	78	77	40	158	97	100	21	72
Ferguson et al. (2015) [28]													
Kitui													
6 to 8 m/o													
Optimized diet	NR	NR	168	127	172	106	157	205	146	114	100	31	41
Worst-case scenario	NR	NR	43	59	42	37	73	49	47	46	24	5	18
Final FBR	NR	NR	132	97	131	72	113	118	81	71	80	19	26
9 to 11 m/o													
Optimized diet	NR	NR	216	144	145	114	184	160	107	179	100	33	41
Worst-case scenario	NR	NR	41	59	41	36	72	47	44	43	22	6	18
Final FBR	NR	NR	174	112	133	86	135	75	78	133	82	21	30
12 to 23 m/o													
Optimized diet	NR	NR	193	117	141	125	139	102	88	146	99	66	51
Worst-case scenario	NR	NR	28	45	32	29	99	24	25	30	14	15	25
Final FBR	NR	NR	133	87	119	75	104	61	81	83	65	55	43
Vihiga													
6 to 8 m/o													
Optimized diet	NR	NR	231	100	132	98	136	119	361	184	68	21	35
Worst-case scenario	NR	NR	71	59	58	38	65	68	76	76	40	5	16
Final FBR	NR	NR	155	79	125	72	111	93	368	147	75	13	31
9 to 11 m/o													
Optimized diet	NR	NR	194	161	201	126	174	186	341	208	87	31	45
Worst-case scenario	NR	NR	71	71	58	48	54	69	87	69	36	8	17
Final FBR	NR	NR	117	85	121	72	105	95	310	120	70	14	31
12 to 23 m/o													
Optimized diet	NR	NR	262	116	165	100	144	101	305	212	86	60	61
Worst-case scenario	NR	NR	60	51	49	37	51	38	50	63	27	16	25

Table 3 (continued)

	Protein	Fat	Vit A (RE)	Thiamine	Riboflavin	Niacin	Vit B6	Folate (DFE)	Vit B12	Vit C	Calcium	Iron	Zinc
Final FBR	NR	NR	183	72	128	60	104	67	275	161	76	41	43
Hlaing et al. (2016) [22]													
Optimized diet	228	NR	164	113	109	62	100	87	470	169	66	96	72
Best-case scenario	267	NR	189	139	140	79	138	90	489	241	72	102	78
Worst-case scenario	111	NR	0	20	17	7	39	1	54	62	29	15	31
Final FBR	147	NR	131	34	76	26	48	29	353	95	46	43	41
Tharrey et al. (2017) [31]													
Optimized diet	110	NR	74	22	49	22	34	19	36	92	32	16	34
Final FBR	210	NR	242	47	121	41	74	74	307	122	76	40	70
Kujinga et al. (2018) [32]													
Best-case scenario	318	132	52	238	154	132	194	110	211	274	158	135	101
Worst-case scenario	41	41	2	105	38	39	82	28	15	7	13	56	66
Final FBR	217	88	25	174	130	108	153	68	169	188	130	98	87
de Jager et al. (2019) [33]													
6 to 8 m/o (BF)													
Best-case scenario	181	214	87	NR	94	92	NR	134	111	101	72	18	50
Worst-case scenario	81	128	81	NR	58	27	NR	70	91	87	46	2	17
Final FBR	207	152	85	NR	93	70	NR	149	108	99	70	17	52
9 to 11 m/o (BF)													
Best-case scenario	178	204	98	NR	109	107	NR	136	139	124	69	24	55
Worst-case scenario	177	108	76	NR	57	30	NR	69	85	81	43	3	20
Final FBR	158	115	90	NR	96	80	NR	115	126	110	57	21	51
12 to 23 m/o (BF)													
Best-case scenario	251	179	181	NR	123	123	NR	112	96	154	75	65	147
Worst-case scenario	108	82	68	NR	51	40	NR	40	60	72	33	17	59
Final FBR	239	108	94	NR	110	86	NR	110	84	130	68	58	145
12 to 23 m/o (NBF)													
Best-case scenario	316	162	36	NR	103	212	NR	124	7	79	46	104	210
Worst-case scenario	131	21	0	NR	28	57	NR	22	2	0	7	36	80
Final FBR	334	80	21	NR	85	160	NR	136	6	51	41	103	221
Samuel et al. (2019) [34]													
Tigray													
6 to 8 m/o													
Optimized diet	130	161	115	126	148	104	100	112	122	125	82	37	24

Table 3 (continued)

	Protein	Fat	Vit A (RE)	Thiamine	Riboflavin	Niacin	Vit B6	Folate (DFE)	Vit B12	Vit C	Calcium	Iron	Zinc
Best-case scenario	137	170	115	128	149	106	101	113	122	125	83	37	25
Worst-case scenario	107	145	101	44	66	39	41	49	48	110	54	5	17
Final FBR	115	160	114	112	141	94	81	98	122	114	81	32	22
9 to 11 m/o													
Optimized diet	177	154	133	100	135	58	105	149	122	122	76	72	33
Best-case scenario	194	188	140	109	175	71	119	157	165	130	93	74	36
Worst-case scenario	113	124	94	60	68	39	55	53	45	103	52	11	19
Final FBR	154	156	106	82	146	47	80	126	116	128	89	60	30
12 to 23 m/o													
Optimized diet	212	122	111	96	146	59	108	82	100	178	100	100	65
Best-case scenario	223	138	112	117	161	86	128	87	101	194	110	144	70
Worst-case scenario	143	91	84	60	61	37	66	36	32	91	41	40	24
Final FBR	213	120	110	100	140	70	90	75	100	115	71	86	46
Amhara													
6 to 8 m/o													
Optimized diet	133	160	110	102	131	81	92	99	104	117	78	34	21
Best-case scenario	150	190	119	104	174	82	93	99	157	124	98	35	24
Worst-case scenario	110	147	102	52	83	37	45	51	55	111	61	9	17
Final FBR	148	184	119	91	172	71	70	89	157	121	97	22	23
9 to 11 m/o													
Optimized diet	152	145	115	98	133	68	129	100	100	130	74	52	27
Best-case scenario	179	172	121	108	164	77	140	108	136	139	90	55	33
Worst-case scenario	104	123	94	60	68	42	55	53	45	103	52	11	18
Final FBR	145	154	105	91	153	63	117	82	114	129	87	43	25
12 to 23 m/o													
Optimized diet	117	78	168	146	68	112	99	84	96	99	135	37	117
Best-case scenario	224	131	96	106	149	72	126	100	84	141	78	174	42
Worst-case scenario	152	91	84	65	73	42	65	40	32	94	46	46	24
Final FBR	193	114	96	82	137	60	101	88	84	134	74	144	29
Oromia													
6 to 8 m/o													
Optimized diet	145	164	129	75	106	46	100	90	100	125	69	38	23
Best-case scenario	168	205	139	81	166	61	109	94	162	134	98	45	29
Worst-case scenario	84	144	101	35	62	32	29	44	48	110	53	2	14

Table 3 (continued)

	Protein	Fat	Vit A (RE)	Thiamine	Riboflavin	Niacin	Vit B6	Folate (DFE)	Vit B12	Vit C	Calcium	Iron	Zinc
Final FBR	130	167	108	68	118	47	78	67	95	127	78	31	21
9 to 11 m/o													
Optimized diet	182	161	143	100	155	66	112	106	146	133	80	45	35
Best-case scenario	202	218	156	114	222	100	167	134	233	168	114	51	38
Worst-case scenario	76	122	94	36	60	32	34	44	45	103	50	3	14
Final FBR	148	154	106	88	148	64	91	80	113	131	87	31	30
12 to 23 m/o													
Optimized diet	249	131	223	103	186	75	120	100	131	160	100	135	47
Best-case scenario	265	170	232	116	226	96	163	105	171	192	118	162	53
Worst-case scenario	121	91	84	57	58	33	60	34	32	91	39	42	22
Final FBR	239	125	221	100	174	76	113	97	121	152	93	121	43
SNNPR													
6 to 8 m/o													
Optimized diet	162	156	101	77	153	44	66	84	122	110	100	43	30
Best-case scenario	220	201	118	85	229	53	77	90	190	121	131	44	33
Worst-case scenario	94	145	101	44	65	34	38	47	48	110	54	7	16
Final FBR	151	155	101	72	146	42	59	76	118	110	95	35	28
9 to 11 m/o													
Optimized diet	162	138	171	102	138	66	133	116	100	136	101	77	36
Best-case scenario	212	193	186	122	220	87	191	161	175	164	131	81	40
Worst-case scenario	84	121	94	48	64	33	53	50	45	103	51	11	16
Final FBR	121	128	150	70	128	49	116	93	81	125	97	50	24
12 to 23 m/o													
Optimized diet	251	109	142	110	171	96	118	100	100	123	100	128	62
Best-case scenario	283	173	182	125	207	122	217	130	135	180	114	202	65
Worst-case scenario	90	88	84	43	54	27	61	34	32	91	38	33	17
Final FBR	244	114	112	100	160	81	101	97	121	93	78	108	58
Chileshe et al. (2020) [35]													
1 to 3 y/o													
Scenario 1													
Optimized diet	256	75	97	116	71	193	155	153	183	35	316	68	64
Worst-case scenario	107	24	0	56	33	42	77	28	4	6	39	37	38
Final FBR	255	55	99	92	79	397	152	78	875	34	264	65	57

Table 3 (continued)

	Protein	Fat	Vit A (RE)	Thiamine	Riboflavin	Niacin	Vit B6	Folate (DFE)	Vit B12	Vit C	Calcium	Iron	Zinc
Scenario 2													
Optimized diet	256	75	97	116	71	193	155	153	183	35	316	68	64
Worst-case scenario	107	24	0	56	33	42	77	28	4	6	39	37	38
Final FBR	266	64	99	106	90	409	159	89	88	36	264	67	62
Scenario 3													
Optimized diet	256	75	98	116	71	188	154	153	170	35	316	68	64
Worst-case scenario	107	24	0	56	33	42	77	28	4	6	39	37	38
Final FBR	295	78	116	101	130	353	161	89	820	93	264	67	70
4 to 5 y/o													
Scenario 1													
Optimized diet	166	88	133	82	76	64	133	55	23	27	399	59	47
Worst-case scenario	115	21	0	50	31	37	75	23	3	5	46	39	37
Final FBR	260	53	131	92	70	210	143	80	378	34	387	71	57
Scenario 2													
Optimized diet	166	88	133	82	76	64	133	55	23	27	399	59	47
Worst-case scenario	115	21	0	50	31	37	75	23	3	5	46	39	37
Final FBR	254	55	131	104	81	215	152	85	379	35	387	70	60
Scenario 3													
Optimized diet	166	88	133	82	77	64	133	55	24	28	399	59	47
Worst-case scenario	155	21	0	50	31	37	75	23	3	5	46	39	37
Final FBR	291	69	158	100	113	213	164	85	439	82	390	76	67
Borgonjen-van den Berg et al. (2021) [36]													
Best-case scenario	371	33	56	220	134	103	177	94	110	196	136	123	86
Mejos et al. (2021) [37]													
6 to 8 m/o													
Best-case scenario	159	162	154	149	230	116	143	112	355	150	91	35	65
Worst-case scenario	109	127	71	38	62	25	43	66	133	57	42	5	27
Final FBR	125	127	125	126	175	96	93	91	193	86	58	16	45
9 to 11 m/o													
Best-case scenario	181	176	188	101	193	101	193	118	566	148	94	37	70
Worst-case scenario	106	109	65	37	60	28	41	61	123	52	39	4	29
Final FBR	141	115	136	81	135	67	110	103	244	81	49	21	40
12 to 23 m/o													
Best-case scenario	282	190	271	90	199	111	108	89	526	159	98	67	113

Table 3 (continued)

	Protein	Fat	Vit A (RE)	Thiamine	Riboflavin	Niacin	Vit B6	Folate (DFE)	Vit B12	Vit C	Calcium	Iron	Zinc
Worst-case scenario	119	81	60	31	47	26	18	31	51	42	30	7	39
Final FBR	184	89	228	67	128	59	66	75	237	93	43	34	53
Sayed & Schönfeldt (2022) [38]													
Optimized diet	214	NR	146	182	116	127	136	119	157	201	102	56	66
Kimere et al. (2022) [39]													
Optimized diet	NR	NR	100	77	121	64	100	96	314	192	76	30	88
Best-case scenario	NR	NR	123	84	129	72	128	100	317	231	83	37	101
Worst-case scenario	NR	NR	66	42	45	28	31	37	55	70	30	10	43
Final FBR 1	NR	NR	120	57	130	36	67	73	137	121	95	20	79
Final FBR 2	NR	NR	108	59	68	44	72	66	160	106	47	30	87

FBR Food-Based Recommendations, *NR* Not Reported nutrient intakes ($n=2$), which was iron and zinc, for Kitui infants. In general, nutrient requirements were more likely to be met in infants aged 9 to 11 months than in those aged 6 to 8 months [17, 28, 34]. Protein [17, 34] and fat [34] met the estimated requirements from local foods for infants in all studies reporting data for this age subgroup.

The findings of all the optimized diets suggested that vitamin A was not a concern, except for Colombian children in the study by Tharrey et al. [31]. Zinc remained the nutrient of concern for children aged 12 to 23 months [22, 28, 31, 34, 39], except for Amhara children in the study by Samuel et al. [34]. Zinc achievements did not meet the estimated requirements from local foods, ranging from 34% [31] to 88% [39]. Despite the zinc achievement (117%) of Amhara children, they did not achieve half of the iron requirement (37%) [34]. Moreover, only Amhara children in this age subgroup did not achieve the requirements for riboflavin (68%), vitamins B6 (99%), B12 (96%), and C (99%) [34]. The same study found that iron and zinc achievement improved with age, except for Amhara children. Calcium requirements were not achieved in most of the studies [22, 28, 31, 39], except for the study by Samuel et al. [34]. Similarly, Ferguson et al. [28] showed the lowest number of inadequate nutrient intakes ($n=3$), which was calcium, iron and zinc, for Vihiga children. In contrast, Tharrey et al. [31] showed the highest number of inadequate nutrient achievements ($n=11$) for Colombian children. Protein [22, 31, 34] and fat [34] met the estimated requirements from local foods for children in all studies reporting data for this age subgroup, except for Amhara children.

Only one study was documented for children aged 1 to 3 years [35]. For these children, modeled dietary intakes from local foods were inadequate for vitamin A (97% to 98%), riboflavin (71%), vitamin C (35%), iron (68%), and zinc (64%) in all three scenarios. In the same study, for children aged 4 to 5 years old, the highest achievable %RNI did not reach 100% for thiamine (82%), riboflavin (76% to 77%), niacin (64%), folate (55%), vitamin B12 (23% to 24%), vitamin C (27% to 28%), iron (59%), and zinc (47%) in all three scenarios. All nutrients, except for fat, vitamin A, riboflavin, and calcium, were able to be achieved by older children than by younger children. The study also showed that protein (256% and 166%) met the estimated requirement from local foods for children in this age subgroup, but not fat (75% and 88%).

Meeting the nutrient requirements for iron, zinc, and calcium for children under five is always a challenge. For infants aged 6 to 8 months, the highest achievable %RNI for iron ranged from 21% [28] to 43% [34] and for zinc from 21% [34] to 73% [17]. In contrast, in infants aged 9 to 11 months, the highest achievable %RNI ranged from 28% [17] to 77% [34] for iron and from 27% [34] to 86% [17] for zinc. When comparing the two youngest age subgroups (6 to 8 and 9 to 11 months old), only one study reported a %RNI greater than 50% for iron for the latter age subgroup [34], while another study [17] reported for both age subgroups. In addition to inadequate nutrient achievement for iron and zinc, children aged 12 to 23 months were unable to achieve calcium requirements, except for Ethiopian children [34], ranging from 32% [31] to 99% [28].

Problem Nutrients

Population-level dietary adequacy for a nutrient was defined as a minimized diet value above a cutoff of its RNI [28]. As a result, a cutoff of either 65% [17, 22, 29, 37, 39] or 70% [28, 31–35] of the RNI for the simulated diet with the lowest nutrient content for each nutrient was predicted to ensure nutrient adequacy for nearly the entire population. In this review, a cutoff value of 65% was set as the lower limit. A problem nutrient is further divided into a partial problem nutrient (PPN) and an absolute problem nutrient (APN). A PPN is a nutrient for which the requirement (%RNI) cannot be met 100% in the optimized diets and 65% in the worst-case scenario but can be met 100% in the highest achievable level for that nutrient in the best-case scenario. On the other hand, an APN is a nutrient for which the requirement (%RNI) cannot be met 100% in the optimized diets and 65% in the worst-case scenario, and the highest achievable level for that nutrient cannot be met 100% in the best-case scenario. Out of 14 studies, 10 studies were lacking in nutrient achievement for simulated diets of either one of the components: optimized diet [32, 33, 37], best-case scenario [28, 35], or in combinations [29–31, 36, 38], while only four studies reported all the components [17, 22, 34, 39].

Table 4 shows the summary of problem nutrients of the included studies by age subgroups and regions. Half of the included studies reported problem nutrients in infants aged 6 to 8 and 9 to 11 months [17, 28–30, 33, 34, 37]. In both age subgroups, iron was identified as the problem nutrient in all studies, followed by calcium and zinc in five studies [28, 29, 33, 34, 37]. The problem nutrient status of thiamine (for both age subgroups) and folate (for infants aged 6 to 8 months) was inconsistent across studies. Interestingly, only one study identified riboflavin as an absolute problem nutrient [17]. Thiamine, niacin, folate, and calcium were reported as partial problem nutrients in only two studies [29, 34]. When both age subgroups were compared, nutrient achievement generally improved with age, resulting in fewer problem nutrients. In the only study that included infants aged 6

Table 4 Summary of problem nutrients in the included studies [17, 22, 28–39]

	Protein (g/day)	Fat (g/day)	Vit A (RE) (µg/day)	Thiamine (mg/day)	Riboflavin (mg/day)	Niacin (mg/day)	Vit B6 (mg/day)	Folate (DFE) (µg/day)	Vit B12 (µg/day)	Vit C (mg/day)	Calcium (mg/day)	Iron (mg/day)	Zinc (mg/day)
Skau et al. (2014) [17]													
6 to 8 m/o				black	black			black				black	
9 to 11 m/o				black	black			black				black	
Ferguson et al. (2015) [28]													
Kitui													
6 to 8 m/o												black	black
9 to 11 m/o												black	black
12 to 23 m/o									black			black	black
Vihiga													
6 to 8 m/o											black	black	black
9 to 11 m/o											black	black	black
12 to 23 m/o											black	black	black
Hlaing et al. (2016) [22]													
12 to 23 m/o						black		black			black	grey	black
Vossenaar et al. (2016) [29]													
Settled													
6 to 8 m/o						grey					grey	black	black
9 to 11 m/o												black	black
12 to 23 m/o						grey							black
Pastoralist													
6 to 8 m/o						grey		grey				black	black
9 to 11 m/o						grey						black	black
12 to 23 m/o						grey	grey	grey				grey	black
Agro-pastoralist													
6 to 8 m/o				grey		grey					grey	black	black
9 to 11 m/o				grey		grey					grey	black	black
12 to 23 m/o				grey		black	grey	grey			grey	black	black
Raymond et al. (2017) [30]													
6 to 8 m/o												orange	
9 to 11 m/o												orange	
Tharrey et al. (2017) [31]													
12 to 23 m/o				orange									
Kujinga et al. (2018) [32]													
4 to 6 y/o			black					black					
de Jager et al. (2019) [33]													
6 to 8 m/o (BF)											black	black	black
9 to 11 m/o (BF)											black	black	black
12 to 23 m/o (BF)											black	black	
12 to 23 m/o (NBF)			black						black	black	black		
Samuel et al. (2019) [34]													
Tigray													
6 to 8 m/o											black	black	black
9 to 11 m/o						black					black	black	black
12 to 23 m/o						black		black					black
Amhara													
6 to 8 m/o						black	black	black			black	black	black
9 to 11 m/o						black					black	black	black
12 to 23 m/o			black			black		grey	black		black		black
Oromia													
6 to 8 m/o				black		black		black			black	black	black
9 to 11 m/o						grey						black	black
12 to 23 m/o						black							black
SNNPR													
6 to 8 m/o				black		black	black	black				black	black
9 to 11 m/o						black						black	black
12 to 23 m/o													black
Chileshe et al. (2020) [35]													
1 to 3 y/o		black									black	black	black
4 to 5 y/o		black									black		black
Borgonjen-van den Berg et al. (2021) [36]													
4 to 6 y/o			black					black					black
Mejos et al. (2021) [37]													
6 to 8 m/o											orange	orange	orange
9 to 11 m/o											orange	orange	orange
12 to 23 m/o				orange				orange			orange	orange	
Sayed & Schönfeldt (2022) [38]													
6 to 11 m/o											orange	orange	orange
Kimere et al. (2022) [39]													
12 to 23 m/o				black		black		grey			black	black	grey

The black box represents an absolute problem nutrient; the grey box represents a partial problem nutrient; the orange box represents a problem nutrient status that is undetermined because it is not reported to 11 months, calcium, iron, and zinc were identified as problem nutrients [38].

Of the 14 included studies, eight reported problem nutrients for children aged 12 to 23 months [22, 28–30, 33, 34, 37, 39]. Iron and calcium were identified as the problem nutrients in all studies, except Raymond et al. [30] and Tharrey et al. [31], followed by zinc in five studies [22, 28, 29, 34, 39], folate in five studies [22, 29, 34, 37, 39], and niacin in four studies [22, 29, 34, 39]. The problem nutrient status of vitamin B12 was inconsistent across studies. Surprisingly, only one study identified vitamin B6 [29] and vitamin C [33] as partial and absolute problem nutrients, respectively. Thiamine, niacin, vitamin B6, folate, calcium, iron, and zinc were reported as partial problem nutrients in four studies [22, 29, 34, 39].

Based on the findings of Chileshe et al. [35], fat, calcium, iron, and zinc were identified as absolute problem nutrients for children aged 1 to 3 years, while fat, calcium, and zinc were identified for children aged 4 to 5 years. For children aged 4 to 6 years, vitamin A and folate were identified as absolute problem nutrients [32, 36]. Not only these two nutrients but also zinc (achieving 86% RNI in the best-case scenario) was identified as an absolute problem nutrient in one of the studies [36].

Final Set of Locally Appropriate FBRs

Individual FBRs selected for screening in Module 3 of Optifood were identified in two ways: (i) food groups that had a higher number of servings of foods in the Module 2 nutritionally best diet (no food pattern) than the median observed for those food groups (food pattern); and (ii) individual food items that provided more than 5% of the nutrient content for at least two micronutrients in the Module 2 nutritionally best diet, generally expressed at their food subgroup level. Once selected, they were combined for testing in a systematic analysis. All possible combinations of the selected FBRs were tested. To select the best set of FBRs for a particular target group, the minimized 7-day dietary nutrient values for all sets of combined individual FBRs tested were compared, and the set/s of FBRs that had the highest number of RNI cutoff values (in %) for the lowest number of FBRs per set and lowest cost were selected.

Table 5 summarizes the final set of locally appropriate FBRs from the included studies. Of the 14 studies, only five reported the final set of FBRs for infants aged 6 to 8 months [17, 29, 33, 34, 37]. The number of FBRs per set ranged from three sets [17, 29] to six sets [33, 37]. In some studies, food items were specified in the final FBRs, including WinFood – a type of small indigenous fish species with bones and edible spider [17], potato or green banana [29], soybean flour [33], and fortified infant cereal food product [34]. As reported by Skau et al. [17], it was a challenge to cover the nutrient gaps for thiamine, riboflavin, folate, and iron even after the introduction of improved complementary products. It was further agreed by Vossenaar et al. [29] that the contribution of niacin, iron, and zinc remained low for most age subgroups. Similarly, optimized local diets did not provide adequate iron and zinc in all regions and age groups [34]. Meat, fish, and eggs were only reported in one study [17], while fruits were excluded as they were rarely consumed by infants [34].

Only one study reported the final set of FBRs for infants aged 6 to 11 months [28]. While some of the FBRs represent only minor changes to current food patterns, others represent more substantial changes, such as feeding infants fortified cereals (once daily) and meat, fish, and eggs (once daily) in Kitui and small fish (5 times weekly) in Vihiga. Interestingly, calcium was a problem nutrient for all infants in Vihiga but not in Kitui, which may be due to the reported use of a commercial millet flour mix with added calcium only in Kitui.

Similar to infants aged 6 to 8 months, the same studies reported the final set of FBRs for infants aged 9 to 11 months [17, 29, 33, 34, 37]. The number of FBRs per set ranged from three sets [29] to seven sets [37]. As reported by Skau et al. [17], the problem nutrients remained the same for the reported age subgroup. Vitamin A was not identified as a problem nutrient due to the food source of vitamin A, which was morning glory – a type of green leafy vegetable that is commonly consumed by the Cambodian population [17]. After optimization, calcium was no longer a problem nutrient for infants in Tigray and Amhara in Ethiopia, while niacin, iron and zinc were still problem nutrients [34]. Bakery products and breakfast cereals were reported in one study [17], and meat, fish, and eggs were rarely included in the final FBRs [17, 33, 37].

More than half of the included studies reported the final set of FBRs for infants aged 12 to 23 months [22, 28, 29, 31, 33, 34, 37, 39]. The number of FBRs per set ranged from three sets [29] to eight sets [37]. In some studies, food items were specified in the final FBRs, including millet flour and goat's milk [28], roselle leaves [22], liver [22, 37], chicken giblets [31], cowpea [33], and sweet potato [39]. The FBRs for infants aged 12 to 23 months were similar to those for infants aged 9 to 11 months, with a few additions and modifications [28]. Although the final set of FBRs in the study by Hlaing et al. [22] did not achieve the nutrient gaps for niacin, folate, calcium, iron, and zinc, it was the most promising set of all the possible combinations, indicating that alternative interventions are needed to ensure dietary adequacy of all nutrients. In addition, after a trial of improved practices,

Table 5 Summary of the final set of locally appropriate FBRs of the included studies

Per Week	Grains and Grain Products	Starchy Roots and Other Starchy Plant Foods	Bakery and Breakfast Cereals	Fruits	Vegetables	Meat, Fish and Eggs	Legumes, Nuts and Seeds	Milk and Milk Products	Others
Skau et al. (2014) [17]									
6 to 8 m/o				3	9	21			Breastfeed on demand WinFood—7
9 to 11 m/o			1	5	14	16			Breastfeed on demand WinFood—8
Ferguson et al. (2015) [28]									
Kitui									
6 to 11 m/o	Millet flour—7		Fortified cereals—7		DGLV—7	Once daily*	Once daily*	Full fat cow's or goat's milk—21	Breastfeed on demand
12 to 23 m/o	Millet flour—7		Fortified cereals—7		DGLV—7	7 (of which small fish—3)	Legumes—14	Full fat cow's or goat's milk—21	Breastfeed on demand
Vihiga									
6 to 11 m/o	Bean flour—7		Fortified cereals—3		DGLV—7	Small fish—5		Full fat cow's or goat's milk—14	Breastfeed on demand
12 to 23 m/o	Legume or bean flour—7		Fortified cereals—4		DGLV—14	Small fish—5		Full fat cow's or goat's milk—21	Breastfeed on demand
Hlaing et al. (2016) [22]									
12 to 23 m/o			Fortified cereal-based beverages—5	7* (roselle leaves—1)	7* (roselle leaves—1)	7 (of which liver—1, anchovy—1, and eggs—2)	Beans and lentils—3		Breastfeed on demand
Vossenaar et al. (2016) [29]									
Settled communities									
6 to 8 m/o		Potato or green banana—7		Potato or green banana—7			Beans—7	Animal milk—14	
9 to 11 m/o	7	Potato or green banana—14		Potato or green banana—14			Beans—8	Animal milk—14	
12 to 23 m/o	7	Potato or green banana—14		Potato or green banana—14			Beans—8	Animal milk—21	
Pastoralist communities									
6 to 8 m/o	7	Potato or green banana—7		Potato or green banana—7	7			Animal milk—14	Vitamin A-fortified fats—7

Table 5 (continued)

Per Week	Grains and Grain Products	Starchy Roots and Other Starchy Plant Foods	Bakery and Breakfast Cereals	Fruits	Vegetables	Meat, Fish and Eggs	Legumes, Nuts and Seeds	Milk and Milk Products	Others
9 to 11 m/o	7	Potato or green banana—10		Potato or green banana—10	7			Animal milk—14	Vitamin A-fortified fats—6
12 to 23 m/o	14	Potato or green banana—10		Potato or green banana—10	14			Animal milk—21	Vitamin A-fortified fats—7
Agro-pastoralist communities									
6 to 8 m/o		Potato or green banana—7		Potato or green banana—7			Beans—6	Animal milk – 12	
9 to 11 m/o		Potato or green banana—5		Potato or green banana—5			Beans—7	Animal milk – 14	
12 to 23 m/o		Potato or green banana—3		Potato or green banana—3			Beans—7	Animal milk—17	
Tharrey et al. (2017) [31]									
12 to 23 m/o					Vitamin A-rich—7	Chicken giblets—3	Legumes—7	14 (of which cow's milk—7)	
Kujinga et al. (2018) [32]									
4 to 6 y/o	14	7			14 (of which vitamin A-source—7 and vitamin C-source—7)	Small whole fish without bones—7	Nuts and seeds—4	Fluid or powdered milk—7	
de Jager et al. (2019) [33]									
6 to 8 m/o (BF)			Soybean flour—7		21		Nut and seeds—7 Beans—14	7	Breastfeed on demand
9 to 11 m/o (BF)	21			7	DGLV—14	Fish—21	Beans—7		Breastfeed on demand
12 to 23 m/o (BF)	7			7	DGLV—14		Nut and seeds—21 Beans—14 (of which extra cowpea—7)	7	Breastfeed on demand
12 to m/o (NBF)	7				DGLV—14	Fish—7	Nut and seeds—21 Beans—14 (of which extra cowpea—7)		Breastfeed on demand

Table 5 (continued)

Per Week	Grains and Grain Products	Starchy Roots and Other Starchy Plant Foods	Bakery and Breakfast Cereals	Fruits	Vegetables	Meat, Fish and Eggs	Legumes, Nuts and Seeds	Milk and Milk Products	Others
Tigray									
6 to 8 m/o	4		Fortified cereals—7					7	Breastfeed on demand
9 to 11 m/o	7				7		Legumes—14	7	Breastfeed on demand
12 to 23 m/o	14				3 to 4	Eggs—7	Legumes—14	7	Breastfeed on demand
Amhara									
6 to 8 m/o			Fortified cereals—7				Legumes—7	7	Breastfeed on demand
9 to 11 m/o	14	Starchy roots—7					Legumes—7	7	Breastfeed on demand
12 to 23 m/o	14	Starchy roots—7			14		Legumes—21	7	Breastfeed on demand
Oromia									
6 to 8 m/o	7	Starchy roots—7					Legumes—7	3 to 4	Breastfeed on demand
9 to 11 m/o	14				14		Legumes—3 to 4	3 to 4	Breastfeed on demand
12 to 23 m/o	14				14	Eggs—7	Legumes—14	3 to 4	Breastfeed on demand
SNNPR									
6 to 8 m/o	14						Legumes—21	3 to 4	Breastfeed on demand
9 to 11 m/o	35	Starchy roots—3 to 4			DGLV—7		Legumes—14	3 to 4	Breastfeed on demand
12 to 23 m/o	21					Eggs—7	Legumes—21	7	Breastfeed on demand
Chileshe et al. (2020) [35]									
1 to 3 y/o	7				21 Rape leaves—7	Small whole fish without bones—2	Beans, lentils and peas—3 Nuts and seeds—4	Mabisi—7	

Table 5 (continued)

Per Week	Grains and Grain Products	Starchy Roots and Other Starchy Plant Foods	Bakery and Breakfast Cereals	Fruits	Vegetables	Meat, Fish and Eggs	Legumes, Nuts and Seeds	Milk and Milk Products	Others
4 o 5 y/o	6				21 Rape leaves—7	Small whole fish without bones—2	Beans, lentils and peas—3 Nuts and seeds—5	Mabisi—6	
Borgonjen-van den Berg et al. (2021) [36]									
4 to 6 y/o	21			7	28	7	4	8	Added fats—7
Mejos et al. (2021) [37]									
6 to 8 m/o	4			3	6		Legumes—3		Breastfeed on demand Liver—1
9 to 11 m/o	6			4	7	Eggs—3	Legumes—3		Breastfeed on demand Liver—1
12 to 23 m/o				7	13	Eggs—3 Fish—3	Beans—3		Breastfeed on demand Liver—1 Fortified beverage—1
Kimere et al. (2022) [39]									
FBR 1		Sweet potatoes—7		14	DGLV—4		Legumes—14	14	
FBR 2	14	Sweet potatoes—7			DGLV—4	7	Legumes—14		

The number in the table indicates the number of weekly serving for each food group. For example, fortified cereals—7 indicates 7 servings of fortified cereals weekly

FBR Food-Based Recommendations, *DGLV* Dark green leafy vegetables

* Either one of the recommended food groups should be met

most mothers (80%) in Myanmar reported that their children would be willing to include chicken liver in their daily diet. Across different communities, vegetables were found to be included only in pastoralist communities for the reported age subgroup [29]. A Ghanaian study found that the addition of seven servings of cowpeas per week improved calcium and iron adequacy in breastfed infants aged 12 to 23 months and iron adequacy in non-breastfed infants [33]. However, none of these nutrients were above 70% of the RNI in the minimized diets. In the study by Kimere et al. [39], the frequency of good food sources, including cow's milk and green leafy vegetables, was doubled in the repeat analysis series, resulting in an increase in the number of nutrients achieving > 65% of their RNIs in the worst-case scenario, from 7 to 8 of 11 micronutrients. However, thiamine, niacin, and iron remained the problem nutrients in infants aged 12 to 23 months.

As presented by Chileshe et al. [35], the final set of FBRs, with the addition of Mabisi – a type of sour milk – improved most of the nutrients in the worst-case scenario, except iron (67%) for children aged 1 to 3 years, as well as fat (69%) and zinc (67%) for children aged 4 to 5 years in Zambia. Two studies reported the final set of FBRs for children aged 4 to 6 years [32, 36]. Without recommendations and zinc-fortified water, %RNI ranged from 40 to 76% for zinc but improved to 66% to 101% after the addition of zinc-fortified water [32]. Based on the results, the final set of FBRs achieved 87% of the zinc requirement but failed to achieve 70% for vitamin A (25%) and folate (68%) in the worst-case scenario.

Discussion

Over the years, the LP approach has been used to develop FBRs in several countries, including Canada [40], Sweden [41], and Brazil [42]. It is particularly useful for countries where population-specific local FBRs, after modifying current dietary patterns to increase the consumption of specific, nutrient-dense foods, could significantly improve dietary patterns and nutrient intakes among vulnerable groups. Undeniably, user-friendly Optifood software is proving to be a valuable tool for predicting the impact of a nutrition intervention on dietary adequacy while simplifying the complicated process of running the LP models used in the study and minimizing the chance of error. It is also a powerful tool for identifying nutrient gaps in the diet and developing FBRs to improve dietary adequacy. Through the application of Optifood, numerous studies have demonstrated the potential to improve dietary adequacy by making minimal changes to food recommendations that are consistent with current dietary practices, particularly in socioeconomically disadvantaged populations [29, 33, 38].

Most of the studies included in this review were conducted in low-income countries with high food vulnerability [17, 22, 28–30, 32–39]. This is likely because research on dietary optimization and nutrient gaps is often prioritized in populations where malnutrition and food insecurity are more prevalent. In such settings, identifying cost-effective and feasible dietary strategies is crucial for improving nutritional outcomes. Studies from countries with less vulnerable populations were scarce, possibly because there is less focus on optimizing diets in populations with better food availability and diversity.

Although progress has been made in achieving dietary adequacy, it is well recognized that in most low-income countries, locally available foods do not meet nutrient requirements, particularly for micronutrients. This has contributed to micronutrient deficiencies and undernutrition, which in turn leads to impaired child growth and development as a long-term health consequence [43]. It is always debatable whether optimizing the intake of locally available foods helps to minimize nutrient gaps and overcome problem nutrients. The presence of problem nutrients remains a challenge in developing healthy, balanced, affordable, and culturally acceptable dietary recommendations for young children, even after optimizing the intake of locally available foods. This scoping review summarizes the existing published data, not only on problem nutrients but also on the potential of locally available foods to meet all nutrient requirements when the diets are optimized by using modeling techniques.

Based on the findings of this review, with the exception of iron and zinc, the majority of nutrient requirements can be achieved when optimizing diets by increasing the feeding quantities or frequencies of nutrient-dense foods identified in each individual study. The findings of this review are in line with those of earlier studies [44, 45], in which the problem nutrients identified were calcium, iron, and zinc. Moreover, this review suggests that across different age subgroups and settings, dietary requirements for iron and zinc were unable to be achieved, even when dietary optimization was applied using locally available foods, within the constraints of food quantity and feeding frequency. Dietary adequacy for the aforementioned micronutrients was met only when fortified foods or home fortification products, such as micronutrient powders (MNPs) or small quantities of lipid-based nutrient supplements (sq-LNS), were introduced into the model [17]. However, in some cases, other micronutrients, such as thiamine, riboflavin, niacin, folate, and calcium, also failed to meet the requirements. The quality of protein or fat was not discussed in any of the studies in this review, despite the growing body of research demonstrating the significance of protein and fat in the growth and development of infants and young children [46, 47].

Several limitations of the dietary and Optifood analyses were acknowledged. First, the studies included in this review relied on assumptions regarding breast milk intake and its nutrient content. The amount of breast milk intake was estimated and included in the daily diet of all recruited children. Therefore, there is a significant difference between actual intakes and modeled breast milk consumption with the possibility of affecting the conclusions. As a result, the assumption that individual-level errors of over- and underestimation of breast milk intake would be balanced at the population level might be incorrect. Second, the small sample size was listed as a limitation, especially for dietary data, as nutrient-dense foods may have been missed [17].

Data were collected in regions with a high prevalence of child undernutrition, where children in several of the communities examined in the studies included in this review were either moderately malnourished or at risk of becoming malnourished. This limits the generalizability of the findings on problem nutrients and nutrient-dense foods based on the dietary data collected. In addition, dietary reference values, including RNIs and EARs, may underestimate, while adequate intakes (AIs) may overestimate, the actual nutrient requirements for optimal growth and development in malnourished children. These reference values for micronutrients are based on the requirements of healthy children rather than malnourished children [48–50]. As reported in October 2008 Proceedings of the World Health Organization, "*the nutritional requirements of moderately malnourished children probably fall somewhere between the nutritional requirements for healthy children and those of children with severe acute malnutrition during the catch-up growth phase*" [51].

The LP model parameters that defined the lower and upper food pattern constraint levels for the optimized 7-day diets were derived from a single multiple-pass 24-h dietary recall. Based on the findings, this is the preferred approach, especially in low- and middle-income countries, where repeated dietary assessments can be resource-intensive and challenging to implement. However, this approach has both random and systematic errors, including participant recall bias, interviewer bias, and portion size estimation [36]. It is undeniable that recall bias is unavoidable when collecting dietary intake data using 24-h dietary recall, as it allows for the selection of more foods from less regularly consumed food groups, such as vegetables, than would normally occur. As a result, this could lead to an underestimation of the number of problem nutrients or an overestimation of the number of nutrients for which dietary adequacy is not achieved [28]. Moreover, nutrient-dense foods that are consumed infrequently, such as snacks and fruits, are often forgotten by reporters.

The use of estimated frequencies of food and food (sub)group instead of reported frequencies increased the modeled frequencies in the draft FBRs [36]. As reported, estimated frequencies have increased the minimum and maximum frequencies for food and food (sub)group that are used as LP model input data. By using estimated frequencies, the maximum frequencies of food and food (sub)group might be overestimated, as the food consumption on the day of data collection does not necessarily reflect the daily consumption in the previous week prior to data collection. As a result, the modeled frequencies may be too high to be accepted by the target population.

The nutrient composition of the food items modeled in most studies was obtained from different food composition databases [17, 22, 35]. The nutrient composition of several potential food items was missing from the Tanzanian Food Composition Tables, resulting in researchers obtaining food composition databases from other countries [30]. The nutrient composition of foods varies greatly depending on regional factors, including soil conditions, agricultural activities, and food processing [19], which may have led to errors. In addition, the nutritional composition of foods is known to vary between regions and countries [52]. This could affect the results of the study, especially if the nutrient composition data of foods promoted in the final selected FBRs were inaccurate. Additionally, food composition tables often overlook the food matrix's role in nutrient bioavailability; for example, phytates in whole grains reduce iron absorption, while vitamin C enhances it. Cooking methods further influence nutrient retention, as boiling depletes water-soluble vitamins, whereas fat-soluble vitamins become more bioavailable when cooked with oil. In addition to food composition databases, some dietary data were collected using average recipes of mixed dishes [17]. As reported, mixed dishes in Cambodia consist of many different ingredients, making it difficult to accurately assess which parts of the mixed dishes were consumed by children.

Next, seasonality was not taken into account in the analysis of the included studies. In most of the studies, dietary intake and food consumption patterns were assessed during the dry season at the study location. This limits the accuracy of the minimum and maximum weekly food consumption pattern model constraints, as well as the generalization of the findings to other seasons in the study area. Therefore, in-depth research is required to evaluate the impact of climate change on the food availability and dietary practices of the study population. In addition, some foods may not be available to all local families involved or at all times. The diet optimization approach using LP uses only reported foods from dietary recalls for the development of FBRs. This may limit the inclusion of certain foods, such as seasonal fruits and vegetables, in a healthy and balanced diet in the final formulation.

One of the limitations experienced with the use of Optifood was the inability to account for factors that influence food choices, including eating habits, behaviors, and social pressure. Some of the studies have addressed this issue by including foods that are consumed by at least 3 to 5% of the study population. However, some of the foods may not be practical for part of the population. For instance, fortified cereals may be too expensive, especially for low-income communities. It is generally accepted that diets supplemented with micronutrient powders can cost three to eight times as much as diets based on nutritious local foods [53]. In addition, the inflexibility of the Optifood real-time manipulation and the inability to customize the output were major drawbacks. It was not possible to manipulate the data after the diet had been checked, and the data output could not be edited in any way.

Another notable limitation is the paucity of studies focusing on children aged 2 to 5 years, despite the broader scope of this review covering children under five. Most existing research predominantly addresses infants and younger children below age of 2, leaving a gap in understanding the dietary inadequacies and optimal food-based recommendations for older children. Future studies, particularly experimental research such as randomized controlled trials (RCTs), are needed to validate the effectiveness of LP-based optimized diets in improving dietary intake and nutritional status, ensuring their practicality and real-world impact.

In addition to fortification and supplementation, improving the availability and accessibility of healthy and nutrient-dense foods requires a comprehensive approach that includes food production policies. National policies that support sustainable agriculture, enhance local food production, and promote the cultivation of nutrient-rich crops can help bridge dietary gaps, particularly in low-income communities. Strengthening supply chains, reducing post-harvest losses, and investing in food distribution networks can further improve food accessibility. Moreover, strategies such as food subsidies, school feeding programs, and community-based nutrition interventions can enhance dietary diversity and affordability. Incorporating these measures together with LP-based dietary optimization can create a more sustainable and effective approach to addressing nutrient deficiencies among vulnerable populations.

Conclusion

In conclusion, despite these limitations, the findings on dietary inadequacy of nutrient intake are remarkably consistent across studies conducted in different geographic and socioeconomic settings. Although these limitations may affect the magnitude of the nutrient gaps, they do not alter the overall conclusion of this review. The review emphasizes that modeled diets based on locally available foods are insufficient in meeting the requirements for certain micronutrients, particularly iron and zinc, even after careful selection of food combinations. The use of LP modeling together with other cost-effective strategies, such as fortification, supplementation, and improvements in food production policies, is likely to play a crucial role in advancing the development and promotion of practical interventions to improve the dietary adequacy of infants and young children. A comprehensive public health nutrition policy should be formulated to improve the dietary adequacy of undernourished children. Moreover, the establishment of financial support systems is imperative to assist the population, particularly low-income families.

Abbreviations

FBRs	Food-based recommendations
LP	Linear programming
RNI	Recommended Nutrient Intakes
DGLV	Dark green leafy vegetables
MFE	Meat, fish and eggs

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Not applicable

Authors' contributions

Study concept and design: Y.X.M., W.Y.G.; researched data: Y.X.M., W.K.H.M.; analysis and interpretation of data: Y.X.M., W.K.H.M., W.Y.G., P.Y.L.; drafting of the manuscript: Y.X.M., W.K.H.M. All authors reviewed and edited the manuscript and approved the final version.

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Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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