Can moringa- and spirulina-enriched foods meet the micronutrient needs of young children?

Study I: Scoping review

Study Report

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Content

List of acronyms

Acronym	Description
AIs	Adequate intakes
CI	Confidence interval
CSB	Corn/soy blend
EAR	Estimated average requirement
EU	European Union
FAO	Food and Agriculture Organisation
FCF	Formulated complementary foods
Hb	Haemoglobin
LMICs	Low- and middle-income countries
MUAC	Mid-upper arm circumference
NRF	Nutrition Research Facility
RAE	Retinol activity equivalent
RNI	Recommended Nutrient Intake
RUF	Ready-to-use food
SCSB	Spirulina Corn Soy Blend
SMEs	Small and medium-sized enterprises
TE	Tocopherol equivalents
UNICEF	UN Children's Fund
WAZ	Weight-for-age z-score
WFP	World Food Programme
WHO	World Health Organisation

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Executive summary

The World Health Organization (WHO) recommends exclusive breastfeeding for infants up to six months. After this, complementary feeding is recommended due to increased nutritional requirements which breast milk solely is unable to meet. In low- and middle-income countries (LMICs), the complementary feeding period often coincides with growth faltering due to low-quality foods and recurrent infections. Complementary foods, particularly cereal-based ones, are the primary source of food available for infants and young children in many low-income African countries, like Chad. Unfortunately, they often fail to meet infants' nutritional needs, leading to deficiencies in key nutrients. Therefore, micronutrient deficiencies and malnutrition remain a major problem for this age group. Cost-effective and sustainable approaches to improve complementary feeding are necessary to ensure child health and reduction of malnutrition rates. LMICs, however, often have locally available nutrient dense foods that have a potential of improving formulated complementary feeding through enrichment. This study therefore explores the potential effects of using two such locally produced nutrient-rich foods, moringa leaves and spirulina, as a food-based approach to enhance the nutritional quality of complementary foods to improve child's health outcomes. The study addresses two main objectives.

First, the nutritional composition of commonly fed porridges and locally available nutrient-rich foods, such as moringa and spirulina, was assessed based on a review of the literature. This objective assessed the nutritional value of both complementary and other nutrient-rich foods available locally. It also assessed the contribution of local porridges to nutrient requirements and identified the amount of the problem nutrients they provided based on the nutrient value from the local complimentary foods and the nutritional requirements of young children.

Second, a scoping review was done to summarise the global evidence on the benefits and risks of using moringa leaves powder and spirulina to enrich young children' diets, focusing on their effects on nutritional status and health outcomes. Additionally, the review summarised the acceptability of enriched or supplemented formulated flours by children and their parents, based on different formulations of complementary foods using various quantities of spirulina and moringa. This review provides a comprehensive report on the knowledge gaps identified in moringa and spirulina use as nutrient dense food in enrichment of local cereal-based complimentary foods.

In Chad, MANISA, a fortified infant cereal-legume flour with a micronutrient premix (this flour is produced with the support of the EU-funded P2RSA programme in Chad), provides the highest micronutrient levels, particularly iron, zinc, manganese, niacin, vitamin D, and copper. Sorghum-based flour was superior to corn-based flour in iron and iodine content. Adding moringa and spirulina could enhance micronutrient density, with spirulina significantly increasing iron levels and moringa improving folate and calcium. However, key deficiencies persist, including vitamin D, iodine, and zinc. Spirulina, which is rich in protein and iron, still lacks essential micronutrients and covers only 22% of zinc needs. Despite improvements, problematic nutrients still lack, especially for older children, requiring additional supplementation strategies.

Although no research was found specifically conducted in Chad, existing literature shows that moringa-enriched complementary foods are generally well accepted, with high approval rates among children (82–87%). Locally sourced moringa porridges are generally well-received by both infants and caregivers. However, adherence to moringa supplementation varies, with enriched porridges showing the highest adherence over time (59%), followed by porridges sprinkled with moringa leaf powder (52%). Both formats were consumed less consistently than the unenriched cereal-legume blend porridge (88%), while spirulina supplementation demonstrated excellent adherence.

Moringa supplementation had no significant impact on overall health, though some studies reported increased diarrhoea and respiratory symptoms. Spirulina-enriched flour reduced respiratory infections but did not significantly decrease other illnesses.

Neither moringa nor spirulina supplementation significantly improved haemoglobin levels, growth, or nutritional status, except for one study showing improved haematocrit levels with spirulina.

In conclusion, enriching cereal-based flours with locally sourced, nutrient-dense foods like moringa and spirulina can help reduce micronutrient deficiencies in children aged 6–24 months. While they improve iron and vitamin B6 content of infant diets, they do not fully address all key deficiencies. Therefore, they should be used alongside other complementary nutrition strategies for a more effective approach.

Box 1. Key messages

- ***While unfortified cereal-based porridges provide protein and energy, they lack essential micronutrients for young children. Moringa and spirulina improve nutrient density but remain insufficient.***
- ***Combining moringa and spirulina with complementary ingredients like groundnut paste, animal-based foods, and fortified or vitamin A-rich ingredients can enhance nutritional value.***
- ***Moringa is well accepted in flour mixes, making it a viable option for food-based interventions. However, research on spirulina's acceptability remains limited.***
- ***Supplementation with moringa and spirulina had no significant effects on haemoglobin concentrations, iron and retinol status, growth, or overall health.***
- ***Study variations in population, design, and dosage highlight the need for more research on the potential benefits of locally sourced food-based strategies.***

Background and context

In Chad, *Moringa oleifera* production remains mainly for self-consumption and/or for retail in the local markets, while spirulina production has been promoted over the last years by the government and some donors and technical agencies (European Union, EU; Food and Agriculture Organisation, FAO). The EU supports the production and commercialisation of nutritious complementary foods for 6-23 months old children (formulated complementary foods, FCF). Leveraging this potential market and responding to the EU's request, the present study explores the potential of using these locally produced nutrient-rich foods to enrich food aimed for the consumption by young children, but also in some cases, by pregnant and lactating women. In this report, young children refer to those between 6 to 24 months of age.

After consultations with the EU Delegation to Chad, the Nutrition Research Facility (NRF) carried out two studies, that are complementary: 1) NRF RS-23.006 i titled “Can moringa- and spirulina-enriched foods meet the micronutrient needs of young children?”; and 2) NRF RS-23.006 ii. titled “Addressing economic and logistical barriers to the adoption of local alternatives (moringa and spirulina) for fortified food production by small and medium enterprises (SMEs) in Africa: a case study of Chad with strategic recommendations”.

The objective of the present study was to explore the potential effects of using locally produced nutrient-rich foods, such as moringa leaves and spirulina, to enhance the nutritional quality of complementary foods and improve child’s health outcomes in Chad.

Introduction

WHO recommends exclusively breastfeeding infants, starting from the first hour of life until 6 months [1]. By the age of six months, breastmilk is no longer sufficient to meet the increased nutritional requirements of young children, ushering the critical period of complementary feeding between 6 and 24 months of age. Complementary foods are the non-breast-milk components of foods and/or energy-containing liquids consumed by young children between the ages of 6 months to 2 years, while they are still breastfeeding [2]. During this critical period, most growth faltering, i.e. stunting, underweight, and wasting begins in LMICs [3]. Growth faltering occurs because of the low quality and/or quantity of complementary foods and recurrent infections. In settings where complementary foods are based on cereals only, meeting the micronutrient needs of young children remains a challenge [4].

The estimated amounts of energy and nutrients required from complementary foods are obtained from calculations based on the difference between 1) the total energy and nutrients requirement of children and 2) the amount of energy and nutrients provided by the intake of breastmilk at three age-groups (6 to 9, 9 to 11, and 11 to 23 months) [2]. These estimates are slightly different based on whether the indicator applied is “nutrient requirement intakes” or “adequate intakes” (AIs) [5]. These inconsistencies are related to the lack of data to establish estimated average requirement (EAR) necessitating the use of other approaches to obtain dietary reference intakes [5]. However, in all these cases there is a clear gap between the nutrient requirements and their provision by complementary foods.

The problem nutrients are defined as “those for which there is the greatest discrepancy between their content in complementary foods and the estimated amount required by the child” [2, 5, 6]. Problem nutrients differ depending on the child’s age category, country, and the indicator used. Overall, calcium, iron, zinc, vitamin B6 are often deficient, while vitamin A, folic acid, and other water-soluble B vitamins are problem nutrients in some populations [5]. The technical update of the WHO/UNICEF reported that complementary foods of infants and young children (6-9 months) are deficient in most micronutrients in Bangladesh and Ghana [5]. The studied micronutrients included vitamin A, calcium, iron, zinc, riboflavin, thiamine, niacin, folate, vitamin B6, and vitamin C. At the same time, complementary foods were found to be sufficient in vitamin A and vitamin C in Guatemala and Peru [5]. Complementary foods of 9-11 months old children were deficient in most of the micronutrients in the four populations, while they were sufficient in zinc at 11-23 months of age.

Young children's diets in rural sub-Saharan Africa often have low dietary diversity and a heavy reliance on white corn, which is high in starch and low in essential nutrients [7]. As a result, complementary foods typically have poor micronutrient content, as key sources of these nutrients—such as animal-based foods (e.g., eggs, meat, and organ meats), legumes, fruits, and vegetables—are often limited. In many poor rural areas, families primarily depend on porridge, which not only has a low nutrient density but is also consumed in insufficient quantities and provided at inadequate meal frequencies, as observed in Benin [8]. The micronutrient content of these complementary foods often falls short of the EARs for infants.

Methods to increase the nutritional content of complementary foods include the promotion of a diversified diet, the provision of fortified complementary foods, the point-of-use fortification or supplementation, and/or the use of nutrient enriched crops of commonly consumed foods [6]. In this context, locally available, affordable nutrient-rich foods could constitute an alternative for complementary food enrichment, such as moringa leaves and spirulina. Few studies explored the potential of adding moringa leaf powder or spirulina to complementary foods for young children, in order to meet their nutritional requirements [9, 10].

Specific objectives

The objectives of the present study are:

1- To estimate the potential of moringa- or spirulina-enriched complementary foods in meeting the nutrients required in 6-24 months aged young children in Chad.
2- To summarise the available evidence on the effects of moringa- or spirulina-enriched foods on the nutritional status and general health of young children 6-24 months of age.

Methodology

The present study addresses two objectives:

First objective: Can moringa- and spirulina-enriched local complementary foods meet the micronutrient needs of young children?

Based on the estimations provided by the Institute of Medicine on the EARs or AIs of young children, the difference between intakes and requirements without enrichment and after enrichment with moringa and spirulina was estimated [9, 10]. Additionally, we compared between a) moringa- and spirulina-enriched cereal-based flour and b) flour which is fortified with Premix of micronutrients, in order to answer the question on the potential of using spirulina and moringa as an alternative to micronutrient Premix.

Second objective: Effects of moringa- and spirulina-enriched or supplemented cereal-based foods on young children's nutritional status and overall health - Scoping review

A scoping review of existing studies was conducted with a critical assessment, including:

- Identification of the current reviews and intervention studies that tested the effectiveness of enriched foods or supplementation with moringa or spirulina on the nutrition status and health of young children.
- Identifying what is known and what is not, especially regarding the acceptability by consumers and different formulations of complementary foods.

We searched three databases—MEDLINE, CENTRAL, and Web of Science—on October 24, 2024, for relevant studies. Eligible studies included those involving infants and young children that examined moringa or spirulina supplementation and measured indicators of acceptability, nutritional status, or micronutrient levels **(Annex 3)**.

Results

Nutrient requirements from complementary foods

To determine the amount needed from complementary foods at different ages, the average amount of each nutrient that is provided by breast milk [2, 5] is subtracted from the total nutrient requirement reported by the 2006 estimates [11, 12] **(Table 1)**. Negative values indicate that breast milk alone exceeds the nutrient requirements of the breastfed infant or young child.

Table 1: Micronutrient requirements, estimated intakes, and requirements from complementary foods by age[1]

	EAR/AI[2]		Breastmilk nutrients[3]		Required from complementary foods[4]		% Required from complementary foods[5]	
Nutrient	6-11 mo	12-23 mo	6-11 mo	12-23 mo	6-11 mo	12-23 mo	6-11 mo	12-23 mo
Vitamin A (μg RE/day)	500*	210	308	274	192	**-64**	38.4	**-30.5**
Folate (μg/day)	80*	120	52	47	28	73	35.0	60.8
Thiamine (μg/day)	300*	400	100	100	200	300	66.7	75.0
Riboflavin (μg/day)	300*	400	200	200	100	200	33.3	50.0
Niacin (mg/day)	4*	5	1	1	3	4	75.0	80.0
Vitamin B_6 (μg/day)	300*	400	57	51	243	349	81.0	87.3
Vitamin B_{12} (μg/day)	0.5*	0.7	0.6	0.5	**-0.1**	0.2	**-20.0**	28.6
Vitamin C (mg/day)	50*	13	25	22	25	**-9**	50.0	**-69.2**
Vitamin D (μg/day)	10	10	0.3	0.3	9.7	9.7	97.0	97.0
Vitamin E (mg/day)	5*	5	1.5	1.3	3.5	3.7	70.0	74.0
Vitamin K (μg/day)	2.5*	30*	1.3	1.2	1.2	28.8	48.0	96.0
Calcium (mg/day)	260*	500	172	154	88	346	33.8	69.2
Copper (μg/day)	220*	260	200	100	20	160	9.1	61.5
Iodine (μg/day)	130*	65	68	60	62	5	47.7	7.7
Iron (mg/day)	6.9	3.0	0.2	0.2	6.7	2.8	97.1	93.3
Magnesium (mg/day)	75*	65	22	19	53	46	70.7	70.8
Manganese (mg/day)	0.6*	1.2*	0.004	0.003	0.6	1.2	100.0	100.0
Phosphorus (mg/day)	275*	380	86	77	189	303	68.7	79.7
Potassium (mg/day)	700*	3000*	323	288	377	2712	53.9	90.4
Zinc (mg/day)	2.5	2.5	0.7	0.7	1.8	1.8	72.0	72.0

[1]EAR, estimated average requirement; AI, adequate intake.
[2]Recommended intakes are for breastmilk and complementary foods based on Institute of Medicine EARs or AIs, as available. AIs are followed by an asterisk (*) [11, 12].
[3]Breastmilk nutrient content estimated based on average breastmilk quantity and composition for each age [2, 5].
[4]The average amounts of nutrients that should be provided from complementary foods have been calculated based on differences between their EAR/AI and their amounts provided by breast milk, by age.
[5]Proportion of nutrients that should be provided by complementary foods, relative to the EAR/AI, based on the difference between estimated breast milk contributions and age-specific requirements.

Nutrient composition of the premix, moringa leaf powder, and spirulina

The nutrient composition of the premix, moringa leaf powder, and spirulina is summarised in **Table 2**. When comparing nutrient contents, supplementation with 5 mg of moringa, 5 mg of spirulina, or a combination of both (2.5 mg each) resulted in a range of 0% (for vitamin D3 and iodine) to 667% (for vitamin B12) relative to the premix. Notably, all enrichment scenarios remained insufficient in zinc (only 1% of the premix level), as well as in all other B-complex vitamins, vitamin C, and vitamin E. Although spirulina is a rich source of iron;

the combined mix provided only 29% of iron compared to the premix, assuming an iron content equivalent to 10 mg (2.5 of NaFeEDTA and 7.5 mg of Ferric pyrophosphate micronized or Ferrous bisglycinate or Ferrous fumarate) of the premix.

Table 2: Nutrient composition of the premix, moringa leaf powder, and spirulina

Nutrients	Premix[1]	Moringa leaves powder [13][2]	Spirulina [14][2]	5 g moringa[3]	5 g spirulina[3]	2.5 g moringa and 2.5 g spirulina[3]
Vitamin A (RAE, µg)	400	3640	18000	46	225	135
Thiamine (mg)	0.5	2.6	4.82	26	48	37
Riboflavin (mg)	0.5	1.2	3.93	12	39	26
Niacin (mg)	6	8.2	39.3	7	33	20
Vitamin B6 (mg)	0.5	2.4	0.91	24	9	17
Folic acid (µg)	90	540	73	30	4	17
Vitamin B12 (µg)	0.9		240	0	1333	667
Vitamin C (mg)	30	172	0	29	0	14
Vitamin D3 (µg)	5			0	0	0
Vitamin E (TE, mg)	5	5.6	10.6	6	11	8
Iron (mg)	10.0	32.5	83.3	16	42	29
Calcium (mg)		1900	70.5			
Magnesium (mg)		473	278			
Phosphorus (mg)			921			
Potassium (mg)			1520			
Copper (mg)	0.56		0.26	0	2	1
Iodine (µg)	90			0	0	0
Zinc (mg)	4	2.4	1.04	3	1	2

[1]Daily dose of premix.
[2]Composition per 100 g dry matter.
[3]Proporition compared to the daily dose of premix.

Nutrient composition of local infant formula and local-rich foods

Most of sub-Saharan African infants' first complementary foods are typically cereal-based porridges with minimal enrichment from local legumes, milk, or dried fish powder [15]. In Benin, most complementary foods consist of corn, millet, or sorghum porridges, often poorly mixed with legumes. These porridges have very low energy density, ranging from 36 to 64 kcal per 100 ml in various countries, including Burkina Faso, Gabon, and the Republic of Congo making them inadequate for infant nutrition [15].

We report the nutrient composition of (1) basic corn-based porridge, (2) red-sorghum local infant formula, (3) MANISA, (4) corn-based flour mix enriched with 5% moringa leaf powder, (5) corn-based flour mix enriched with 5% spirulina, and (6) corn-based flour mix enriched with 2.5% moringa and 2.5% spirulina **(Table 3)**. The nutrient content of the formulation of the corn-based flour mixes, sorghum-based flour mix, corn-based flour mix with 5% moringa, corn-based mix with 5% spirulina, and corn-based mix with moringa and spirulina (2.5% each) is based here on recipe calculation from known values of ingredients obtained from west African food composition tables and are not based on laboratory analysis [16-18]. Therefore the results are an approximation and may vary from a lab analysis [16].

The steps undertaken for the recipe calculation involved calculation principles of the total recipe method from EuroFIR (step 1-7), Intake, and FAO recipe calculation method [16, 18, 19]. The yield factor was obtained from known water to cereal ratios for corn-based porridge flour and nutrient retention factors from Bognar table and were applied at the recipe level. The retention factor of the whole recipe is based on the food group of the main ingredient in this case corn flour [16, 18-20]. MANISA nutrient values were obtained from the joint programme implemented by the Centre d'Excellence Regional Contre la Faim et la Malnutrition and the World Food Programme (WFP) in Chad [19]. The composition of the premix and the nutritional profiles of moringa and spirulina are detailed in **Table 2**. Our estimates were based on the composition of moringa [17, 21] and spirulina [14] as reported in the literature. Due to the lack of dietary data on cereal-based porridges in Chad—including their energy density, composition, frequency of consumption, and serving sizes—we based our analysis on 100 g servings per day. We considered three examples, along with the nutritional composition of moringa leaves and spirulina from the literature **(Table 4)**. Bioavailability was not accounted for.

Table 3: Nutrient composition of selected cereal-based flour mix and per 100g cooked porridge[1]

Nutrient	Corn-based flour mix[2]	Sorghum-based flour mix[3]	MANISA[4]	Corn-based flour mix with 5% moringa[5]	Corn-based flour mix with 5% spirulina[6]	Corn-based flour mix with 2,5% moringa & 2,5% spirulina7	Corn-based flour mix[2]	Sorghum-based flour mix[3]	MANISA[4]	Corn-based flour mix with 5% moringa[5]	Corn-based flour mix with 5% spirulina[6]	Corn-based flour mix with 2,5% moringa & 2,5% spirulina7
	100 g dry ingredients						**100 g cooked porridge**					
Energy (kcal)	392	389	379	387	391	397	98	97	95	97	98	99
Protein (g)	8.2	13.1	14.7	9.4	11.7	11.2	2.1	3.3	3.7	2.4	2.9	2.8
Fat (g)	9	8.5	9.6	9	9.4	9.2	2.2	2.1	2.4	2.2	2.4	2.3
Iron (mg)	1.4	3.9	26.5	3	5.5	5.1	0.3	1	6.6	0.8	1.4	1.3
Zinc (mg)	1.5	1.5	11.3	1.6	1.5	1.6	0.4	0.4	2.8	0.4	0.4	0.4
Magnesium (mg)	63.1	49	167.4	86.7	77	93.7	15.8	12.2	41.9	21.7	19.2	23.4
Manganese (mg)			1.8		0.2	0.1			0.45		0.05	0
Phosphorus (mg)	187.3	106.7	279.5	187.3	233.3	210.3	46.8	26.7	69.9	46.8	58.3	52.6
Potassium (mg)	254.5	180.1	613.7	254.4	330.4	292.4	63.6	45	153.4	63.6	82.6	73.1
Calcium (mg)	23.5	46.7	243.6	118.4	26.9	120.2	5.9	11.7	60.9	29.6	6.7	30
Iodine (µg)			211.2						52.8			
Vitamin A (µg RAE)	0.3	0	611.1	182.3	900.3	632.3	0.1	0	152.8	45.6	225.1	158.1
Vitamin C (mg)	0.2	0.2	25.3	8.8	0.2	8.8	0	0	6.3	2.2	0.04	2.2
Thiamine (mg)	0.3	0.2	0.5	0.5	0.6	0.6	0.1	0	0.1	0.1	0.1	0.1
Riboflavin (mg)	0.1	0.1	0.4	0.1	0.3	0.2	0.01	0.02	0.1	0	0.1	0.1
Niacin (mg)	3.4	4.8	6.5	3.8	5.3	4.8	0.8	1.2	1.6	0.9	1.3	1.2
Vitamin B_6 (mg)	0.3	0.1	0.7	0.4	0.3	0.4	0.1	0.02	0.2	0.1	0.1	0.1
Folate (µg)	45.9	35.7	143.5	72.9	49.6	74.7	11.5	8.9	35.9	18.2	12.4	18.7
Vitamin B_{12} (µg)	0	0	0.5	0	12	6	0	0	0.1	0	3	1.5
Vitamin D (µg)	0	0	105.1	0	0	0	0	0	26.3	0	0	0
Vitamin E (mg)	1.7	1.3	8.7	4.5	2.2	4.7	0.4	0.3	2.2	1.1	0.5	1.2
Vitamin K (µg)			42.1		111	55.5			10.5		27.8	13.9
Copper (mg)	0.3	0.1	0.8	0.3	0.3	0.3	0.1	0.03	0.2	0.1	0.1	0.1

Cell colours indicate nutrient content: green = highest, yellow to orange = average, red = lowest.

[1]Nutrient composition is reported per 100g of dry ingredients, and per 100 g cooked porridge. Proportions were harmonised to have 3 portions of water for one portion of the infant flour.

[2]Basic porridge constituted from typical ingredients in west Africa, containing (100 g dry mix): corn flour (70 g), peanut (15 g), sugar (15 g).

[3]Based on the composition of typical ingredients of local flours from Chad, containing (100 g dry mix): 60 g red sorghum flour, 15 g beans, 15 g peanut butter paste, 9 g sugar, and 1 g iodise salt [22].

[4]Based on the composition reported on the label. MANISA flour contains corn, soja, peanut, niébé, sugar, iodised salt, and premix.

[5]Based on basic porridge and 5% moringa leaves powder, containing (100 g dry mix): corn flour (70 g), peanut (15 g), sugar (10 g), and moringa leaves powder (5 g). Moringa composition is based on the analysis reported by Boateng et al. [13].

[6]Based on basic porridge and 5% spirulina, containing (100 g dry mix): corn flour (70 g), peanut (15 g), sugar (10 g), and spirulina (5 g). Spirulina composition is based on the analysis reported by Silva et al. [14].

[7]Based on basic porridge and 2.5% moringa leaves powder and 2.5% spirulina.

Table 4: Estimated percentage (%) of EAR/AI required from complementary foods covered by 100 g cooked porridge, by age group

Nutrient	Corn-based flour mix[2]	Sorghum-based flour mix[3]	MANISA[4]	Corn-based flour mix with 5% moringa[5]	Corn-based flour mix with 5% spirulina[6]	Corn-based flour mix with 2,5% moringa & 2,5% spirulina7	Corn-based flour mix[2]	Sorghum-based flour mix[3]	MANISA[4]	Corn-based flour mix with 5% moringa[5]	Corn-based flour mix with 5% spirulina[6]	Corn-based flour mix with 2,5% moringa & 2,5% spirulina7
	6-11 months						12-23 months					
Iron (mg)	5.1	14.4	98.9	11.2	20.7	19.0	12.3	34.5	236.6	26.8	49.5	45.4
Zinc (mg)	22.2	20.3	156.3	22.4	21.5	22.8	22.2	20.3	156.3	22.4	21.5	22.8
Magnesium (mg)	29.8	23.1	79.0	40.9	36.3	44.2	34.3	26.6	91.0	47.1	41.8	50.9
Manganese (mg)	0.0	0.0	74.2	0.0	7.9	4.0	0.0	0.0	37.1	0.0	4.0	2.0
Phosphorus (mg)	24.8	14.1	37.0	24.8	30.9	27.8	15.4	8.8	23.1	15.4	19.2	17.3
Potassium (mg)	33.7	23.8	81.2	33.7	43.7	38.7	21.0	14.9	50.6	21.0	27.3	24.1
Calcium (mg)	6.7	13.3	69.2	33.6	7.6	34.1	1.7	3.4	17.6	8.6	1.9	8.7
Iodine (µg)	0.0	0.0	85.2	0.0	0.0	0.0	0.0	0.0	1056.0	0.0	0.0	0.0
Vitamin A (µg RAE)	0.1	0.0	79.6	23.7	117.2	82.3	-0.2	0.0	-238.7	-71.2	-351.7	-247.0
Vitamin C (mg)	0.0	0.2	25.3	8.8	0.2	8.8	0.0	-0.4	-70.3	-24.3	-0.4	-24.3
Thiamine (mg)	50.0	20.8	56.6	56.8	70.7	71.9	33.3	13.9	37.7	37.9	47.1	47.9
Riboflavin (mg)	10.0	23.7	101.2	29.5	63.6	54.1	5.0	11.9	50.6	14.8	31.8	27.0
Niacin (mg)	26.7	39.8	54.4	31.4	44.4	39.6	20.0	29.8	40.8	23.6	33.3	29.7
Vitamin B_6 (mg)	41.2	9.4	68.7	42.5	34.9	44.9	28.7	6.6	47.8	29.6	24.3	31.3
Folate (µg)	41.1	31.9	128.1	65.1	44.2	66.7	15.8	12.2	49.1	25.0	17.0	25.6
Vitamin B_{12} (µg)	0.0	0.0	-125.0	0.0	-3000.0	-1500.0	0.0	0.0	62.5	0.0	1500.0	750.0
Vitamin D (µg)	0.0	0.0	270.9	0.0	0.0	0.0	0.0	0.0	270.9	0.0	0.0	0.0
Vitamin E (mg)	11.4	9.5	62.4	31.9	15.7	33.8	10.8	9.0	59.0	30.2	14.8	32.0
Vitamin K (µg)	0.0	0.0	877.1	0.0	2312.5	1156.0	0.0	0.0	36.5	0.0	96.4	48.2
Copper (mg)	500.0	161.1	947.4	312.5	328.8	320.6	62.5	20.1	118.4	39.1	41.1	40.1

Cell colours indicate nutrient content: green = highest, yellow to orange = average, red = lowest.

[1]Nutrient composition is reported per 100g of dry ingredients, and per 100 g cooked porridge. Proportions were harmonised to have 3 portions of water for one portion of the infant flour.

[2]Basic porridge considering typical ingredients in west Africa, containing (100 g dry mix): corn flour (50 g), peanut (10 g), sugar (10 g).

[3]Based on the composition of typical ingredients of local flours from Chad, containing (100 g dry mix): 60 g red sorghum flour, 15 g beans, 15 g peanut butter paste, 9 g sugar, and 1 g iodise salt [22].

[4]Based on the composition reported on the label. MANISA flour contains corn, soja, peanut, niébé, sugar, iodised salt, and premix.

[5]Based on basic porridge and 5% moringa leaves powder, containing (100 g dry mix): corn flour (70 g), peanut (15 g), sugar (10 g), and moringa leaves powder (5 g). Moringa composition is based on the analysis reported by Boateng et al. [13].

[6]Based on basic porridge and 5% spirulina, containing (100 g dry mix): corn flour (70 g), peanut (15 g), sugar (10 g), and spirulina (5 g). Spirulina composition is based on the analysis reported by Silva et al. [14].

[7]Based on basic porridge and 2.5% moringa leaves powder and 2.5% spirulina.

Table 4 presents the estimated percentage of the EAR or AI provided by 100 grams of cooked porridge from various complementary food formulations, across two age groups (6-11 months and 12-23 months). It compares five different formulations: a corn-based flour mix, a sorghum-based flour mix, MANISA (a nutrient-dense fortified blend), a corn-based mix with 5% moringa, and a corn-based mix with 5% spirulina. The table highlights the micronutrient contribution of these porridges, indicating their potential to meet young children's nutritional needs.

In Chad, MANISA, a fortified infant cereal- and legume-based flour that is produced with the support of the EU-funded P2RSA programme and uses premix of micronutrients, provides the highest percentages across most micronutrients, particularly iron, zinc, manganese, niacin, vitamin D, and copper, significantly exceeding daily requirements in some cases. The sorghum-based flour mix also provided significant amounts of micronutrients, especially iron and niacin as compared to the corn-based flour, while corn-based flour was superior to sorghum-based flour regarding thiamine and vitamin B6. The addition of moringa and spirulina enhanced micronutrient density of the flours compared to the standard corn-based mix. Spirulina particularly significantly improved the content of the local corn-based flour mix in iron, vitamin A, thiamine, riboflavin, and vitamin B12. However, some formulations lack or provide minimal amounts of specific vitamins, such as vitamin B12, vitamin D, and iodine. Moringa-enriched corn-based porridge improved folate and calcium content significantly. Enrichment with 5 g moringa leaf powder, results in coverage of 65% and 25% of folate, with coverage decreasing as the child grows older. The main problematic nutrients remain after moringa supplementation including, vitamin B2, iron, and zinc, while folic acid is covered until the age of 12 months.

Spirulina is very rich in protein and iron compared to moringa leaves, while its composition did not include all the micronutrients of interest. The main problematic micronutrient is zinc, whose content in spirulina resulted in a coverage of 22%, regardless of the age group. While other micronutrients also remain insufficient, spirulina is especially rich in vitamin B12. However, two important considerations must be noted. First, for infants aged 6–11 months, breastmilk meets nearly all vitamin B12 needs, resulting in a negative requirement from complementary foods (–0.1 µg/day). For young children aged 12–24 months, only 0.2 µg/day is required from complementary foods. Second, although spirulina is high in vitamin B12 and can raise levels in the blood, it does not support healthy blood cell production because the form of B12 it contains is not usable by the human body and may even disrupt normal B12 function [23].

These figures should be interpreted with caution, as they do not account for factors such as portion size, porridge density and viscosity, frequency of intake, nutrient bioavailability, or potential nutrient losses during cooking if different from the standard retention factors. Additionally, the same "hypothetical" amount of 100 grams of cooked porridge is considered for both age groups, despite likely differences in actual consumption patterns. Thus, while the data provides a useful comparison of nutrient density among different formulations, real-world intake may vary significantly.

Dietary intake analyses from multiple low-income countries indicate that iron, zinc, calcium, selected B vitamins, and, in some cases, vitamin A, are often inadequate in traditional home-prepared complementary foods [24]. A recent study in Bangladesh by Campbell and colleagues found that home-prepared foods did not meet the estimated micronutrient needs of children aged 9–18 months in rural areas [25]. Similarly, a significant proportion of breastfed children aged 6–24 months did not meet the Recommended Nutrient Intake (RNI) or the EAR for most of the 11 key micronutrients assessed, including calcium, iron, zinc, vitamin A, riboflavin, folic acid, and vitamin C [26]. MANISA is the most nutrient-dense formulation, significantly surpassing both the corn- and sorghum-based flour mixes in iron, zinc, calcium, iodine, vitamin A, niacin, and vitamin D, making it highly fortified for optimal nutrition. The sorghum-based mix is superior to the corn-based mix in protein, minerals, and B vitamins, but still falls short of MANISA's nutrient profile. Enriching the corn-based mix with 5% moringa increases vitamin A, calcium, and vitamin C, while 5% spirulina increases protein, iron, and B vitamins. The combination of moringa and spirulina improved the levels of iron, folic acid, and vitamin B12. However, this mix has not been evaluated in any intervention study, and its benefits are based solely on a theoretical model. As such, evidence on its acceptability and effectiveness in improving nutritional status is currently lacking. The only study we found on combining moringa and spirulina focused on formulating a supplement tablet, using a 7:3 ratio [27]. While these enrichments enhance nutritional quality, MANISA remains the most fortified and well-balanced option overall.

Studies included in the scoping review

A total of 17 studies met the inclusion criteria and were included in this review **(Figure 1)**. These studies primarily assessed recipe acceptability through qualitative methods and evaluated the impact of supplementation or enrichment on health and nutritional status. The characteristics of the included quantitative studies are provided in **Table 5**.

Acceptability of moringa leaf powder

Complementary foods enriched with a food supplement composed of 63% *Adansonia digitata* fruit pulp, 15% moringa leaf powder, and 22% *Cochlospermum tinctorium* root powder showed high acceptability, with 85–87% child approval for fortified porridges [28]. Community-based moringa-enriched recipes provided improved nutrition and were moderately to highly accepted compared to alternatives [29]. Dehydrated moringa leaves (5–7 g/100 g) in recipes for 1–5-year-olds also showed high compliance and acceptance [30]. Eighty-two percent of untrained panellists like the cooked porridge fortified with 8.26% of Moringa oleifera in Cameroon [31]. Overall, locally sourced moringa-enriched porridges, either as part of a cereal–legume complementary food blend or when sprinkled as a food supplement were well-received by infants and caregivers [32].

Mode of administration of the supplements

Moringa supplements were provided in powders and mothers were instructed to give the supplements together with foods to their children in the study of Menasria et al., 2018 [33]. Boateng et al. provided moringa leaf powder both in the form of sprinkles to be added to the prepared food while hot, or in an enriched form of cereal-legume blended flour [13].

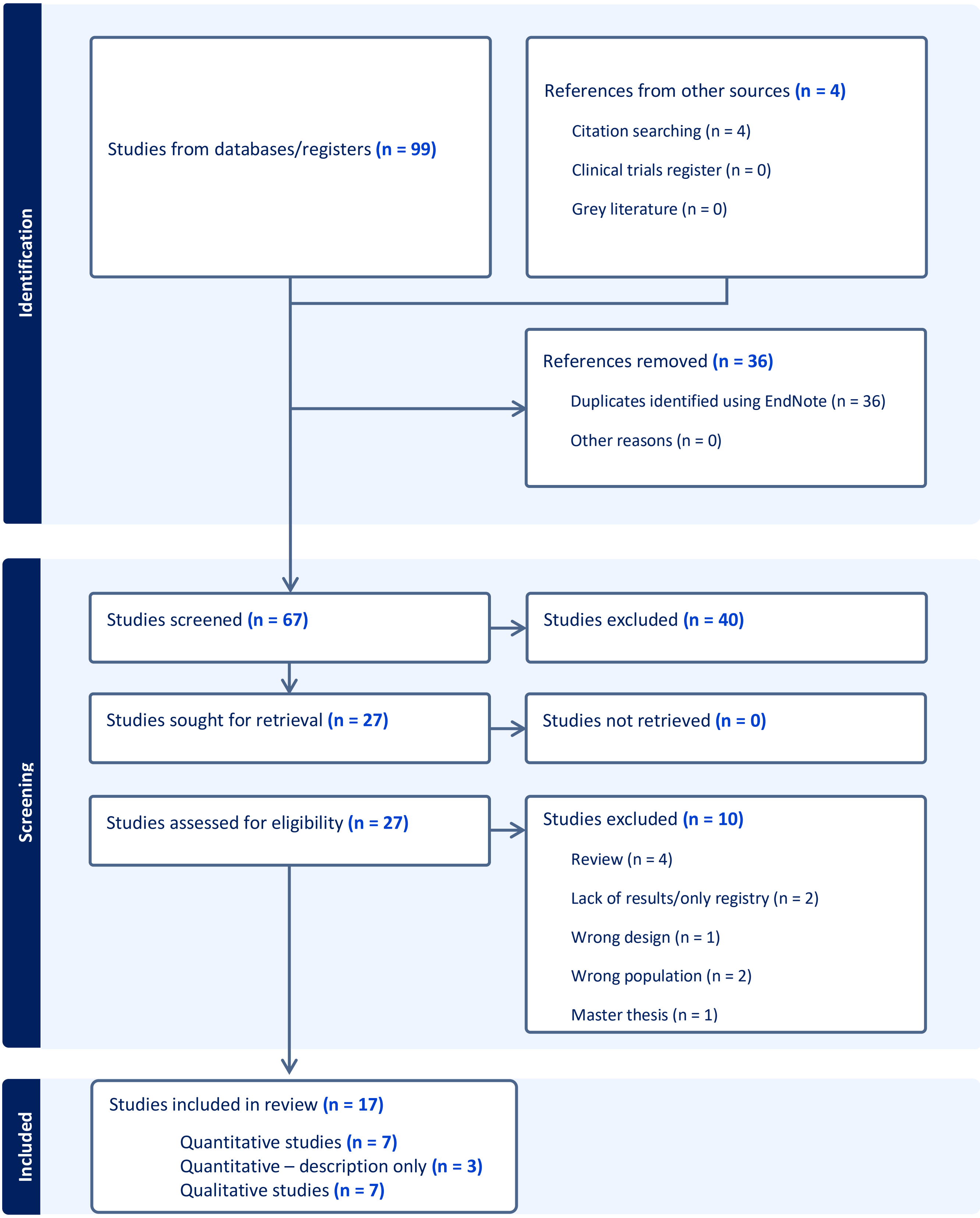

Figure 1. PRISMA study flow diagram for the scoping review.

Table 5: Characteristics of included studies in the scoping review

1.1. Moringa		
Menasria, 2018 Impact of Provision of Local Foods Combined with Nutrition Education and Counselling on Young Child Nutritional Status in Cambodia		
Methods	A cluster-randomised controlled trial was conducted in Soth Nikum area, Cambodia, including 14 villages.	
Participants	children 6–23 months (n = 360) assigned to receive either moringa + nutritional education and counselling (n=120), cricket + nutritional education and counselling (120) or nutritional education and counselling alone (120).	
Interventions	• Moringa group received a daily ration of 16 g of moringa to provide around 1.5 mg of iron daily, which corresponds to around 20% of the daily requirements. Moringa powder contains 388 kcal per 100 g, 33 g of protein, 10 mg of iron, 1.4 mg of zinc and 356 mg of vitamin C. • Nutrition education counselling	
Outcomes/reference of the article reporting on the outcome(s)	Length/height for age z-score and stunting, weight for length/height z-score and wasting, haemoglobin and ferritin concentration Adherence and % satisfaction of nutritional requirements Reported health status	**[33]**
Notes	Exclusion criteria included children with severe anaemia or malnutrition, children from families which may not be present in the area for the entire study period, children from multiple births and those with congenital anomalies.	
Boateng et al., 2018 (ISRCTN14377902) Complementary Foods Fortified with Moringa oleifera Leaf Powder – A Pilot Study		
Methods	A subset of infants participating in a randomised controlled trial, in Ghana	
Participants	Infants aged 8 to 12 months were randomly assigned to receive one of the three study foods (1) moringa-enriched cereal-legume blended flour MCL-35g (n=34), (2) moringa-supplemented cereal-legume blended flour MS-5g (n=34), and a control CF-35g (n=35) in a feeding intervention that lasted for 6 weeks.	
Nutritional interventions	• Moringa leaf powder mixed with a cereal-legume blended flour (MCL-35g). • Moringa leaf powder as a food supplement to be added to infants' usual complementary foods (MS-5g) • A cereal-legume blend complementary food (Weanimx, third arm (CF-35 g) without Moringa leaf powder.	
Outcomes/reference of the article reporting on the outcome(s)	Retinol concentrations Child morbidity	**[13]**
	Haemoglobin concentration and growth of infants and young children after 4 months of feeding.	**[34]**
Notes	Included infants who were still being breastfed, had no congenital abnormalities, and whose mothers or caregivers planned to stay at the study site for the duration of the study. Infants who had known intolerances to any of the ingredients of the study foods were excluded.	
Jilcott et al. 2009 Supplemental Feeding Programme for Underweight Children Ages 6–59 Months in Western Uganda		
Methods	Inpatient feeding program, included 6-59 months of age children in 5 week-10 weeks treatment cycles.	

Participants	215 children 12-37 months whose weight-for-age on the 3rd percentile line on the standard Ugandan immunisation card and/or had a mid-upper arm circumference < 12 cm or had been referred from the World Harvest Mission	
Interventions	Children received a ready-to-use food, an alternative to ready-to-use therapeutic foods, locally produced consisted of 47% roasted peanut paste, 3% dried moringa powder, and 50% roasted soy flour, totalled 900 g, and provided the child approximately 682 kcal per day. Energy density of the supplement was 5.3 kcal/g (21.5 kJ/g) and contained 30 g of protein per 100 g supplement. No control group	
Outcomes/reference of the article reporting on the outcome(s)	Weight gain velocity	**[35]**
Notes	In addition to the ready-to-use foods (RUF), each child received a month's supply of multivitamin, folic acid, and iron tablets, as well as one high dose of vitamin A and a de-worming pill on enrolment.	
Shija et al. 2019 Effect of Moringa Oleifera leaf powder supplementation on reducing anaemia in children below two years		
Methods	A community-based interventional study was conducted in Kisarawe District, Tanzania between October 2014 and July 2015.	
Participants	Anaemic children (n=95) from the intervention communities (n=43) received moringa leaf powder and nutrition education, while control communities (n=52) only received nutrition education for six months.	
Interventions	Mothers/caretakers in intervention communities received monthly 4 bottles of Moringa leaf powder with 200 g each, per child. They were advised to use at least 3 tablespoons (estimated 8 gm) or average of 25 g of Moringa leaf powder per day mixed in their child's daily food.	
Outcomes/reference of the article reporting on the outcome(s)	Changes on mean haemoglobin concentration and anaemia prevalence.	**[36]**
Notes	The project enrolled voluntarily anaemic children (Hb <11 g/dl) of age between 6 months and 17 months from the study communities. Children found with Hb level <6 g/dl were excluded from the study and were referred to the nearest health facility for further appropriate management.	
1.2. Spirulina		
Masuda and Chitundu, 2019 (NCT03523182) Multiple micronutrient supplementation using spirulina platensis and infant growth, morbidity, and motor development		
Methods	An open-labelled randomised control trial was conducted from April 2015 to April 2016 in Zambia among children 6-18 months of age.	
Participants	Eligible children (n=501) were randomised to either the spriulina group (n = 250) or the control group (n = 251).	
Interventions	• Spirulina group received 10 g of spirulina powder daily mixed with 200 g mealie meal and soya flour porridge blend (5%). • Control group received a 70 g mealie meal and soya flour porridge blend, three times a day. The ratio of the blend is 7:1:2 mealie meal:sugar:soya. Both porridges were prepared by mixing 70 g of the flour in boiled water and cooking for 20–30 minutes.	
Outcomes/reference of the article reporting on the outcome(s)	Change in infants' anthropometric status Morbidity (probable pneumonia, cough, probable malaria, and fever) Motor development over 12 months	**[37]**

Notes	Inclusion criteria included: 1) between 6 and 18 months of age, 2) a singleton birth child, 3) residence in the study area, and 4) informed consent from at least one caregiver. Exclusion criteria were: 1) presence of severe illness warranting hospitalisation on the enrolment session day, and 2) enrolment in any other clinical trial.	
Othoo et al. 2021 (PACTR202004842786087) Impact of Spirulina corn soy blend on Iron deficient children aged 6-23 months in Ndhiwa Sub-County Kenya		
Methods	Randomised control trial that assessed a spirulina corn soy blend (SCSB) on iron deficiency anaemia (IDA) among children aged 6–23 months.	
Participants	240 children with IDA were randomly assigned to study groups at a ratio of 1:1:1. The three groups included spirulina corn soy blend (SCSB), corn soy blend (CSB), and placebo flour.	
Interventions	SCSB, CSB and placebo flour (1.7 kg) was given to caregivers to prepare porridges using a flour water ratio of 1:4, producing 600 ml – 700 ml of porridge to feed children 200 ml of porridge three times a day for 6 months.	
Outcomes/reference of the article reporting on the outcome(s)	Recovery from iron deficiency anaemia.	**[38]**
Notes	Children were eligible and recruited if their WAZ: <−2SD to > −3SD, MUAC ≥115-125 mm, Hb ≤12 mg/L, pale conjunctiva and > 3 s capillary palm refill, caregiver consent participation, with no pre-existing conditions like cancer, heart, liver and kidney, not in any intervention and caregiver not planning to move out of the study area during study period.	
Branger, 2003 Spirulina as a food supplement in case of infant malnutrition in Burkina-Faso		
Methods	A hospital-based randomised controlled trial was conducted in Koudougou, Burkina Faso.	
Participants	165 children 3 months to 3 years of age, with malnutrition (weight-for-age z-score < -2 SD or with oedema), were randomly assigned to receive during three months renutrition foods and nutrition counselling (group 1, n=54), renutrition foods and nutrition counselling + 5 g spirulina/day (group 2, n=56), therapeutic foods + 5 g spirulina + fish (group 3, n=55).	
Nutritional interventions	• Group 1: breastfeeding and 1-2 porridges for infants 4–6 months (milk powder, roasted millet, rice, corn, or beans-based flour, monkey bread flour (baobab fruit), néré flour or peanut flour. From 1 year, breastfeeding and 2 porridges with similar ingredients enriched with baobab leaves, oil, shea butter, and dry fish. After 1 year, diet is complemented by Tô. • Group 2: renutrition foods as for Group 1 with 5 g spirulina daily, as a supplement added to the foods. • Group 3: renutrition foods as for Group 1 with 5 g spirulina daily, as a supplement added to the foods and fish (2 sardines in oil weekly).	
Outcomes/reference of the article reporting on the outcome(s)	Weight gain, length/height change, and weight-for-height/length	**[39]**
Notes	Recruitment was done in four sites with a refeeding centre in Koudougou, Nanoro, Reo and Tenado, and one refeeding centre of Amitié Hospital at Koudougou, during November 2000. Children with bone malformities, endocrine diseases or chronic diseases were excluded. Children were not screened for HIV.	
Simpore, 2006 Nutrition rehabilitation of undernourished children utilising Spiruline and Misola in Burkina-Faso		

Methods	Hospital-based randomised control trial that included children under 5 years of age who are admitted for severe malnutrition, in Burkina Faso between 2002–2003.	
Participants	550 children were enrolled randomly in three rehabilitation re-hydration protocols for 8 weeks.	
Nutritional interventions	• Misola only ((731 ± 7 kcal/day, n=170). Misola is a mixture of millet (60%), soya (20%), peanut kernel (10%), sugar (9%) and salt (1%). • Spirulina supplemented to traditional meals that included millet, vegetable, fruit (748 ± 6 kcal/day, n=170) • Spirulina plus Misola (767 ± 5 kcal/day, n=170). • A control group of 40 undernourished children from the same age range was chosen randomly from children whose mothers did not accept the protocol study, received traditional meals (722 ± 8 kcal/day). The vitamin and mineral deficiencies were corrected at the end of study	
Outcomes/reference of the article reporting on the outcome(s)	Anthropometrics including weight-for age, height-for-age, and weight-for-height z scores, and MUAC. Daily weight gain.	**[40]**
Notes	Spirulina groups received weekly rations of Spirulina in a sachet. Every day, they had to mix, two times a day, 5 g of Spirulina with the meal of their children composed of 50 grams of millet flour or 50 g of Misola in a graduated container. The preparation of the Misola or millet was carried out as commonly done in community, namely 50 g of Misola or millet and 200 ml of water were mixed and boiled over a low fire, mixing for 2–3 minutes. Each mother fed own child 4 times a day.	
Simpore, 2005 Nutrition rehabilitation of HIV-infected and HIV-negative undernourished children utilising spirulina in Burkina-Faso		
Methods	Hospital-based cohort study that included children under 5 years of age who are admitted for severe malnutrition, HIV-infected and HIV-negative, in Burkina Faso between 2002–2003.	
Participants	Children with undernutrition, aged 12-60 months (average 14.4)	
Nutritional interventions	Children were provided with their traditional meals at home (outpatient). All children received 10 g of spirulina daily for 8 weeks and their nutritional status was monitored weekly at the medical centre.	
Outcomes/reference of the article reporting on the outcome(s)	Nutritional indices, weight-for age, height-for-age, and weight-for-height z scores. Haemoglobin level, number of leukocytes, lymphocytes and neutrophils were only measured before and after 8 weeks	**[41]**
Notes	Mothers were provided weekly a sachet of 70 g spirulina. They were instructed to mix 10 g of spirulina with a graduated container to the traditional meal of their children composed of millet flour. This mixture was made at least twice a day.	

Table 6: Summary of the outcomes comparing moringa or spirulina supplements to controls

Outcome	Trial-Study	Supplementation rate	Comparison group	Statistical method	Effect size
1- Moringa enrichment					
1.1. Hemoglobin concentrations (g/L)	Menasria et al., 2018 [33][1]	16 g of moringa daily with nutritional education	Nutritional education	Standard mean difference (95% CI)	0.29 [-0.09, 0.67]
	Boateng et al., 2019 [34]	5 g of moringa daily as sprinkles	Weanimix flour	Standard mean difference (95% CI)	-0.09 [-0.40, 0.23]
	Boateng et al., 2019 [34]	5 g of moringa with Weanimix flour	Weanimix flour	Standard mean difference (95% CI)	-0.21 [-0.52, 0.10]
	Shija et al., 2019 [36]	25 g of moringa daily with nutritional education	Nutritional education	Standard mean difference (95% CI)	**0.64 [0.22, 1.05]**
1.2. Ferritin concentrations (µg/L)	Menasria et al., 2018 [33][1]	16 g of moringa daily with nutrition education	Nutrition education	Standard mean difference (95% CI)	-0.06 [-0.44, 0.32]
1.3. Retinol concentrations (µmol/l)	Boateng et al., 2018 [13]	5 g of moringa daily as sprinkles	Cereal legume mix flour	Standard mean difference (95% CI)	0.55 [-0.04, 1.15]
	Boateng et al., 2018 [13]	5 g of moringa mixed with flour	Cereal legume mix flour	Standard mean difference (95% CI)	0.17 [-0.42, 0.76]
1.4. Weight gain	Boateng et al., 2018 [34]	5 g of moringa daily as sprinkles	Cereal legume mix flour	Standard mean difference (95% CI)	-0.06 [-0.18, 0.06]
	Boateng et al., 2018 [34]	5 g of moringa mixed with flour	Cereal legume mix flour	Standard mean difference (95% CI)	-0.16 [-0.30, -0.02]
1.5. Length/height gain					
Length/height gain-for-age z score	Menasria et al., 2018 [33][1]	16 g of moringa daily with nutrition education	Nutrition education	Standard mean difference (95% CI)	0.14 [-0.21, 0.50]
	Boateng et al., 2018 [34]	5 g of moringa daily as sprinkles	Cereal legume mix flour	Standard mean difference (95% CI)	-0.05 [-0.36, 0.26]

	Boateng et al., 2018 [34]	5 g of moringa mixed with flour	Cereal legume mix flour	Standard mean difference (95% CI)	**-0.46 [-0.77, -0.15]**
1.6. weight-for-height z score	Menasria et al., 2018 [33][1]	16 g of moringa daily with nutrition education	Nutrition education	Standard mean difference (95% CI)	0.13 [-0.23, 0.48]
1.7. Health status (healthy)	Menasria et al., 2018 [33][1]	16 g of moringa daily with nutrition education	Nutrition education	Risk ratio (95% CI)	1.20 [0.91, 1.59]
2- Spirulina enrichment					
2.1. Haemoglobin concentrations (g/L)					
Hematocrit levels	Othoo et al., 2021 [38]	0.4% spirulina enriched corn-soy-based porridge	0.4% premix fortified corn-soy-based porridge	Standard mean difference (95% CI)	**1.36 [1.01, 1.71]**
2.2. Weight gain	Masuda and Chitundu, 2019 [37][2]	10 g (5%) of spirulina daily mixed with soy-corn-based porridge	soya-corn-based porridge	Standard mean difference (95% CI)	-0.10 [-0.95, 0.75]
Weight-for-age z-score	Simpore et al., 2006 [40]	10 g/day (10%) of spirulina mixed with traditional porridge	Traditional porridge	Standard mean difference (95% CI)	0.31 [-0.03, 0.66]
Weight-for-age z-score	Simpore et al., 2006 [40]	10 g/day (10%) of spirulina mixed with Misola	Misola	Standard mean difference (95% CI)	0.21 [-0.00, 0.42]
2.3. Length/height gain	Masuda and Chitundu, 2019 [37][2]	10 g (5%) of spirulina daily mixed with soya-corn-based porridge	soya-corn-based porridge	Standard mean difference (95% CI)	0.03 [-0.16, 0.21]
2.4. Weight-for-height z score	Simpore et al., 2006 [40]	10 g/day (10%) of spirulina mixed with traditional porridge	Traditional porridge	Standard mean difference (95% CI)	0.14 [-0.21, 0.48]

	Simpore et al., 2006 [40]	10 g/day (10%) of spirulina mixed with Misola	Misola	Standard mean difference (95% CI)	-0.02 [-0.23, 0.19]

CI, Confidence interval; CSB, Corn/Soy blend; MUAC, Middle-upper arm circumference.

*****Favors the control group.

[1]Included only those participants who consumed moringa, at any rate.

[2]Results were reported as means with no standard deviation at baseline. Standard deviation were imputed from baseline characteristics.

Adherence to the enriched flour or the supplement

Two studies reported on adherence to moringa supplementation, and one study examined adherence to spirulina. In a study conducted in a rural district of Ghana, adherence among infants was lowest for moringa-supplemented porridges, with 59% for moringa-enriched porridges and 52% for porridges sprinkled with moringa leaf powder, with no significant difference between the two, compared to an 88% disappearance rate over six weeks for an unenriched cereal-legume blend porridge [13]. Another study found that moringa-enriched foods were consumed less over time [33]. Adherence to spirulina supplementation was excellent, with no children dropping out of the study. In this intervention, 5 g of spirulina was sprinkled onto foods, and mothers reported that children accepted the mixes well and rarely experienced difficulties with feeding [40].

Morbidity and health outcomes

Children who received moringa in any form were not significantly different from those who received controls in terms of being healthy as found by Menasria et al. [33]. Paradoxically, Boateng et al. found that children who received fortified flour with moringa powder reportedly had higher episodes of vomiting, diarrhea, coughing, nasal discharge, and fever compared to children who received unfortified flour, while those who received it as sprinkles did not differ from controls [34]. Moringa powder (25 g) provided as supplements added to the child foods (porridge, vegetable stew, or mashed starchy roots) to under two year children in Tanzania led to reportedly loose stool (90.7%; n = 39), which persisted for an average of 3–4 days [36]. It is important to note that these were pilot studies and were not powered to detect differences in morbidity outcomes. However, the occurrence of loose stools may be attributable to the higher fibre content in the enriched flours. In the study by Boateng et al., the control group had a higher socioeconomic status and better hygienic conditions, including improved sources of drinking water, compared to the moringa-supplemented groups [34]. Further research specifically designed to assess the potential side effects of moringa-enriched flour on morbidity—particularly its impact on diarrhoea—is needed.

Corn-soja-based flour enriched with spirulina prophylactically prevented upper respiratory infection morbidity in the participating infants compared to those who received corn-soja-based porridge solely. However, spirulina did not result in significantly decreased incidence of probable pneumonia, probable malaria, and fever [37].

Effects of supplementation and feeding enriched foods with moringa and spirulina

The outcomes comparing moringa or spirulina supplements to controls are summarised in **Table 6**. Overall, moringa enrichment or supplementation had no significant effect on haemoglobin concentrations [33, 34]; ferritin concentrations [33], or retinol concentrations [13]. Only the study by Shija and collaborators reported a significantly large effect on haemoglobin concentrations after providing 25 mg of moringa daily [36]. Similarly, moringa-based enriched or supplemented foods did not significantly improve weight gain [34], height/length gain [33, 34], weight-for-height z-scores [33], or overall health status [33]. It is noteworthy that while supplementing 5 g of moringa as sprinkles had no effect, providing 5 g moringa leaf powder-enriched porridge resulted in a significantly negative effect on linear growth compared to cereal-legume mix flour [34]. The researchers hypothesised that this could be attributed to lower adherence, reduced food intake due to lower acceptability, and a higher number of reported morbidity episodes associated with the porridge enriched with 5 g of moringa leaf powder [34]. Jilcott et al. evaluated an ongoing feeding programme that provides community-based care to underweight children in a rural Western Ugandan setting, using a locally-sourced and produced ready-to-use food [35]. Children gained in average 2.5 g/kg/day (range 0.9–6.0), which is less than reported by other studies which supplemented ready-to-use therapeutic foods, despite a comparable energy provision [42-45].

Except for the study of Masuda and Chitundu which was conducted on healthy children [37], most of the studies that assessed the effects of spirulina supplementation or enrichment were conducted on children with iron-deficiency anaemia [38], or hospitalised for severe malnutrition [39-41]. Porridge-enriched with spirulina had no significant effects on weight gain [37, 40], length or height gain [37], or weight-for-height z scores [40]. Branger et al. tested the effect of adding 5 g spirulina as a sprinkle to the renutrition feeding for treating children with severe acute malnutrition in Burkina Faso. The study showed no significant effects of supplementing spirulina after 90 days of treatment on weight gain, weight-for-age z-score, and weight-for-height z-score [39]. Only the study by Othoo and collaborators found an extremely large effect on haematocrit levels (a marker of haemoglobin) when providing children with 0.4% spirulina-enriched corn-soy-based porridge compared the 0.4% premix fortified porridge [38].

Main findings

- While unfortified cereal-based porridges provide a good source of protein and energy, they fail to meet the requirements for key micronutrients in young children. Although the addition of moringa and spirulina increased the micronutrient density of the flours, the levels remained insufficient to reach nutrient adequacy.
- A comprehensive approach is essential when addressing micronutrient deficiencies. Enhancing porridges with complementary ingredients such as groundnut paste, animal-based foods, and fortified or vitamin A-rich ingredients can improve their overall nutritional quality, making them more suitable for children across all age groups.
- Moringa demonstrated high acceptability when incorporated into flour mixes, suggesting that it met the organoleptic standards for young children. This high acceptance is key for sustained interventions, making moringa a viable option for food-based strategies to address micronutrient deficiencies in local cereal-based flour mixes. However, research on the acceptability of spirulina-enriched porridges remains limited.
- Overall, porridge enrichment or supplementation with moringa leaf powder and spirulina had no significant effects on hemoglobin concentration, iron and retinol status, physical growth, or the overall health of children.
- The heterogeneity of the study population (including both healthy and unhealthy children), variations in study design, supplementation and enrichment methods, and differences in dosage highlight the need for further research.

Recommendations

- The enrichment with moringa and spirulina is best complemented with an nutrition education approach, also considering food safety, breastfeeding, child caring, and overall diet quality.
- Additional studies are needed to better understand the potential effects of sustainable, locally sourced, food-based interventions. Future research should prioritise the development and testing of locally acceptable formulations, including other nutrient-rich ingredients such as peanut flour. Moreover, the effectiveness of these alternatives on children's nutritional status and health should be evaluated through well-designed community-based randomised controlled trials. These studies should also incorporate detailed dietary assessments to capture nutrient intakes accurately.

Conclusion

This report summarises the nutrient composition of enriched cereal-based flour mixes in low-income countries, aiming to ensure adequate nutritional quality. Utilising locally produced, nutrient-dense foods to enhance complementary flours offers a cost-effective and sustainable strategy for reducing micronutrient deficiencies in children aged 6–24 months. While moringa leaf powder and spirulina contribute to increasing the micronutrient density of cereal-based porridges—particularly for nutrients like iron and vitamin B6—they remain insufficient in addressing all key deficiencies. Therefore, they should be used in combination with other complementary strategies such as nutrition education and value chain.

Additionally, advancements in manufacturing techniques and local production of blended cereal products have made processed foods more accessible and affordable for low-income families. Given the local availability and cultural acceptability of nutrient-rich sources such as moringa leaf powder and spirulina, they present a promising approach to improving micronutrient intake. However, the sustainability of their value chain for local production will be further informed by the findings of the economic study reference no. RS23.006ii.

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List of Annexes

Annex 1: Search strategy

Category	Detail
Population	Young children 6 – 24 months of age
Intervention/Exposure	complementary food enrichment or point-of-use supplementation with moringa leaves or spirulina
Outcome	Nutritional outcomes (including z-scores of physical growth indicators, haemoglobin concentrations, micronutrient status, iron-deficiency anaemia, vitamin A deficiency)
Setting	Low- and middle-income countries with data from Chad
Time-frame	Studies/articles published from 01/01/2000
Language	English, French

Search strategy

Topic	Search no.	Publication type	Topic search	Database
Moringa	**# 1**	Review & systematic review	Moringa Anaemia Nutritional status of infants and young children Micronutrient status including iron, zinc, and vitamin A Infant and young child feeding practices	Pubmed
	# 2	Review & systematic review		Web of science
	# 3	Review	Moringa	Cochrane
Spirulina	**# 1**	Review & systematic review	Spirulina Anaemia Nutritional status of infants and young children Micronutrient status including iron, zinc, and vitamin A Infant and young child feeding practices	Pubmed
	# 2	Review & systematic review		Web of science
	# 3	Review	Spirulina	Cochrane

Table 1. Medline search strategy (tested on October 24th 2024)

ID	Query	Results
#1 Moringa & Spirulina	"Moringa"[MeSH Terms] OR Moringa [tiab] OR "Spirulina"[MeSH Terms] OR Spirulin*[tiab] OR "drumstick tree"[tiab] OR "horseradish tree"[tiab] OR "malunggay"[tiab]	5,823
#2 Anemia and iron deficiency	"anemia"[MeSH Terms] OR "anemia*"[TIAB] OR "anaemia*"[TIAB] OR "anemia, iron deficiency"[MeSH Terms] OR "iron-deficiency"[TIAB] OR "iron binding proteins"[MeSH Terms]	373,210
#3 Nutritional status of infants and young children	"infant nutritional physiological phenomena"[MeSH Terms] OR ("nutritional status"[MeSH Terms] OR ("nutrition*"[TIAB] AND "status"[TIAB])) AND ("infant*"[TIAB] OR "child*"[TIAB])	64,697
#4 Micronutrient status including	(("micronutrients"[MeSH Terms] OR "micronutrient*"[TIAB] OR "micronutriment*"[TIAB] OR "trace elements"[MeSH	27,738

iron, zinc, and vitamin A	Terms] OR ("trace"[TIAB] AND "element*"[TIAB]) OR "Vitamin A"[Mesh] OR "vitamin A"[TIAB] OR "Zinc"[Mesh] OR "Zinc"[TIAB]) AND ("status"[TIAB])) OR "Vitamin A Deficiency"[Mesh]	
#5 Infant and young child feeding practices	("infant"[MeSH Terms] OR "infant*"[TIAB] OR "child"[MeSH Terms] OR "child*"[TIAB] OR "toddler*"[TIAB] OR "baby"[TIAB]) AND ("feed*"[TIAB] OR "food"[MeSH Terms] OR "food*"[TIAB])	196,846
	#1 AND (#2 OR #3 OR #4) AND #5	40

Table 2. Web of Science strategy (tested on October 24th 2024)

ID	Query	Results
#1 Moringa & Spirulina	Ts=("moringa" OR "spirulina" OR "spiruline" OR "drumstick tree" OR "horseradish tree" OR "malunggay")	15,579
#2 Anemia	Ts=("anemia" OR "anaemia")	190,530
#3 Nutritional status of infants and young children	Ts= (("nutrition*" AND "status") AND ("infant*" OR "child*"))	30,137
#4 Micronutrient status including iron, zinc, and vitamin A	Ts= (("micronutrient*" OR "micronutriment*" OR ("trace" AND "element*") OR "iron" OR "vitamin A" OR "Zinc") AND ("status"))	44,885
#5 Infant and young child feeding practices	Ts=(("infant*" OR "toddler*" OR "child*" OR "Baby") AND ("feed*" OR "food*"))	158,855
	#1 AND (#2 OR #3 OR #4) AND #5	36

Table 3. Cochrane search strategy (tested on October 24th 2024)

ID	Query	Results
#1 Moringa & Spirulina	[mh "Moringa"] OR [mh "Spirulina"] OR (Moringa OR Spirulina OR spiruline OR "drumstick tree" OR "horseradish tree" OR malunggay):ti,ab,kw	527
#2 Anemia and iron deficiency	[mh "anemia"] OR [mh "anemia, iron deficiency"] OR [mh "iron binding proteins"] OR (anemia* OR anaemia* OR "iron deficiency" OR "iron-deficiency" OR "iron binding proteins"):ti,ab,kw	28587
#3 Nutritional status of infants and young children	[mh "infant nutritional physiological phenomena"] OR ([mh "nutritional status"] OR ("nutrition*":ti,ab,kw AND "status":ti,ab,kw)) AND ("infant*":ti,ab,kw OR "child*":ti,ab,kw)	9461
#4 Micronutrient status including iron, zinc, and vitamin A	(([mh "micronutrients"] OR [mh "trace elements"] OR [mh "Vitamin A"] OR [mh "Zinc"] OR (micronutrient* OR micronutriment* OR (trace AND element*) OR "vitamin A" OR Zinc):ti,ab,kw) AND (status:ti,ab,kw)) OR [mh "Vitamin A Deficiency"]	4576
#5 Infant and young child feeding practices	([mh "infant"] OR "infant*":ti,ab,kw OR [mh "child"] OR "child*":ti,ab,kw OR "toddler*":ti,ab,kw OR "baby":ti,ab,kw) AND ("feed*":ti,ab,kw OR [mh "food"] OR "food*":ti,ab,kw)	20013
	#1 AND (#2 OR #3 OR #4) AND #5	23

A total of 99 records were identified and sent to Endnote for deduplication. A total of 63 records will undergo screening based on title and abstract.

Annex 2. Excluded studies

Reference	Reason for exclusion
Dagnelie et al., 1991 [23]	Clinical based supplementation on megaloblastic children to test the absorption of vitamin B12.
Smith et al., 2022 [7]	Child Health, Agriculture and Integrated Nutrition (CHAIN). Only protocol published, results not published yet.
https://trialsearch.who.int/Trial2.aspx?TrialID=DRKS00017388 [46]	Nutrient-dense supplemental meals with and without micronutrient sprinkles or micronutrient-rich leaf powder (Moringa/Amaranthus) to reduce the prevalence of anaemia in children living in Birbhum District, West Bengal, India. Only registered protocol.
Kajuju Malla et al. 2022 [47]	Effect of Moringa Oleifera Consumption on Protein and Vitamin A Status of 5-11 years Children with Cerebral Palsy in Nairobi, Kenya
Masuda and Chitundu 2019 [48]	Follow up study- long term effects of supplementing Spirulina to children in their young childhood.
Nida et al. 2020 [49]	Local Regulation as a Nutritional Improvement Solution in Indonesia.
Parlesak et al. 2014 [50]	Formulation of food baskets including moringa to meet nutrient requirements, using linear programming, in Mozambique.