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REVIEW ARTICLE

Recent developments in ready-to-use foods to improve the health status of moderate acute malnourished children

Vanya Pareek[1], Komal Chauhan[1]*, Neetu K Taneja[2], Harinder Singh Oberoi[2] & Heena Yadav[1]

[1]Department of Food Science and Technology, National Institute of Food Technology Entrepreneurship and Management, Kundli, Sonepat 131 028, Haryana, India

[2]Department of Interdisciplinary Sciences, National Institute of Food Technology Entrepreneurship and Management, Kundli, Sonepat 131 028, Haryana, India

*Correspondence email - drkomal.niftem@gmail.com

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Abstract

Despite various government and nongovernment measures, malnutrition (low weight-for-height) remains a global concern among children and its prevalence is alarming. The contention that effective management of moderate acute malnutrition (MAM) prevents severe acute malnutrition (SAM) is supported by data demonstrating substantial reductions in the extent and prevalence of SAM in areas where MAM has been adequately treated. The reduction of childhood morbidity and mortality through an intervention is contingent on the study of foods used to treat children suffering from MAM. Therefore, a narrative review of the literature was conducted, providing a comprehensive background on recent developments in supplementary foods by summarising findings from a total of 17 studies that have the potential to manage MAM. The review also paves the way for possible future inventions. It was observed that the supplementary biscuits developed from local ingredients were more cost-effective and acceptable to children. The inclusion of fish in various forms of supplementary food could serve as a great source of valuable protein. Furthermore, ready-to-use, low-moisture peanut pastes were transformed using indigenous ingredients to make them more acceptable and the use of pre and probiotics in foods to manage malnutrition improved the gut microbiota of children. It was seen that the use of locally available ingredients to develop study foods could serve as an alternative for managing MAM.

Keywords: acute malnutrition; children; moderate acute malnutrition; supplementary foods

Abbreviations

% : percentage, AM: acute malnutrition, CFs: complimentary foods, cm: centimetre, CSB: corn soy blend, CSB + : corn soy blend plus, CSB + + : corn soy blend plus plus, CSB14: corn soy blend 14, DHA: docosahexaenoic acid, DS: dehulled soy, FBFs: fortified blended foods, FER: fat energy ratio, Fig.: figure, FOS: fructo-oligosaccharide, g: gram, GOS: galacto-oligosaccharide, h: hour, HAZ: height-for-age, ITP: intention-to -treat, IVPD: in-vitro protein digestibility, kcal: kilocalories, kJ: kilojoules, L: litre, LMF: locally millet flours mix, LNS: lipid-based nutrient supplement, MAM: moderate acute malnutrition, MDCF: microbiota directed complementary food, MDCF-2: microbiota directed complementary food-2, MI: misola, mL: millilitre, MNP: micronutrient powder, ITP: intention-to-treat, IVPD: *in-vitro* protein digestibility, kcal: kilocalories, kJ: kilojoules, L: litre, LMF: locally millet flours mix, LNS: lipid-based nutrient supplement, MAM: moderate acute malnutrition, MDCF: microbiota directed complementary food, MDCF-2: microbiota directed complementary food-2, MI: misola, mL: millilitre, MNP: micronutrient powder, MUAC: mid upper-arm circumference, n: number of participants, NEWSUP: new supplement, OCG: oligosaccharide control group, OFSP CF-1: orange-fleshed sweet potato complimentary food 1, OFSP CF-2: orange-fleshed sweet potato complimentary food 2, OFSP: orange-fleshed sweet potato, PD: protein digestibility, PER: protein energy ratio, QPM: quality protein maize, RCT: randomized control trial, RSC: red sorghum-cowpea, RUF: ready-to-use food, RUFs: ready-to-use foods, RUSF: ready-to-use supplementary food, RUSFs: ready-to-use supplementary foods, RUTF: ready-to-use therapeutic food, SAM: severe acute malnutrition, SD: standard deviations, SDGs: sustainable development goals, SI: soy isolate, SMP: skim milk powder, SPI: soy protein isolate, T-P/M: taro-peanut/mungbean, T-P: taro-peanut, vs.: versus , WAZ: weight-for-age, WHO: world health organization, WHZ: weight-for-height , WLZ: weight-for-length, WPC: with whey protein concentrate, WSC1: white sorghum-cowpea 1, WSC2: white sorghum-cowpea 2, WSS: white-sorghum soya

Introduction

Malnutrition remains a global concern, especially among children, adversely affecting their cognitive development, growth and overall well-being. According to the World Health Organization (WHO), globally, 148 million children have been reported to be stunted, 45.0 million were wasted and 37.0 million were reported to be overweight (1). Malnutrition (low weight-for-height) poses a serious threat to public health worldwide, especially for children under five. It also hinders global productivity growth and economic progress (2, 3).

Malnutrition, in terms of inadequate nourishment and suboptimal food intake in the early years of life, has a negative and permanent effect on children's intellect, ability to work, longevity and physical and emotional development (4-8).

Furthermore, it is also a significant risk factor for the onset of numerous diseases in children around the world. AM in children under five has not yet reached the target set by the World Health Assembly to reduce the global incidence to less than 5 % by 2025 (9). Sustainable Development Goals (SDGs) 2.2 states, "End all forms of malnutrition in children under five years of age by 2025". Acute malnutrition (AM) significantly raises the probability of mortality; hence, a child who is malnourished has an 11-fold increased risk of death and is 3.4 times more likely to lose their lives as compared to well-nourished children (10, 11).

AM is responsible for about 45 % of deaths worldwide in children under the age of five, with most of these deaths occurring in middle and low-income countries (12). AM is caused by a combination of factors, including poverty, food insecurity, limited access to healthcare and frequent exposure to adverse environmental conditions. Furthermore, successful strategies are hampered by inadequate infrastructure and resources, which causes extended episodes of AM. AM is categorized as moderate acute malnutrition (MAM) or severe acute malnutrition (SAM), depending on its severity (13-15). According to the World Health Organization (WHO), anthropometry is used to define MAM in children (i.e., weight-for-height (WHZ) between -2 and -3 standard deviations (SD) below the WHO Child Growth Standards) and/or mid-upper arm circumference (MUAC) of 11.5-12.5 cm. At the same time, severe acute malnutrition (SAM) is categorized as WHZ <-3 SD, MUAC <11.5 cm, or the appearance of bilateral pitting edema. Children who experience MAM are more likely to suffer fatalities from illnesses, have an increased possibility of developing diseases as adults (8, 16, 17) and may potentially progress to SAM (18-23).

Therefore, to preserve children's growth, wellness and progress to the greatest extent possible, proper nutrition during infancy and early childhood is crucial (24), making it necessary to prioritize health, food and interventions in the early years of life to prevent malnutrition (17). Children with MAM are typically treated with a dietary supplement consisting of mixed flours that have been fortified. The most popular is a corn-soy blend (CSB), the main type of nutritional assistance provided by the United States Department of Agriculture and the United States Agency for International Development, which can be prepared using inexpensive, local and readily available ingredients that are suitable both organoleptically and culturally. Concerns about CSB stemming from its poor micronutrient content, bioavailability and antinutrient content led to the recommendation of a reduced dose of ready-to-use therapeutic food (RUTF) as a ready-to-use supplementary food (RUSF), but the continual scarcity of these nutritional supplements is a significant contributing factor to the low success rate of nutrition programs (25). Even though RUSFs have many advantages, problems like high prices, weak supply chains and scarce funds still exist, especially in emergencies, which make MAM services time-limited or inaccessible (26). The product's paste-like consistency is another reason for its decreased liking (27). Another dietary supplement is a micronutrient-enriched cereal and legume-based product known as "fortified blended foods" (FBFs), which have been the primary form of nutritional assistance offered worldwide for nearly half a century due to their cost-effective nutrition benefits. Yet, their low effectiveness in managing undernourished young children has drawn criticism (28).

MAM children require nutrient-dense diets to meet their needs for height and weight gain, as well as cognitive development (12, 29). Therefore, for its management, alternative RUSF formulations have been developed and tested by various researchers (30). Nutrition regulations and approaches are either merely tools, too widely designed to provide specific direction on policy levers that may be arranged to tackle nutrition issues, or too vaguely customized to combat different kinds of malnutrition, which highlights the need for additional research to optimize the content of supplemental foods, which has been spurred by the apparent high cost and huge quantity required to manage MAM (29, 31, 32).

This narrative review aims to provide a thorough evaluation of the various study foods that have been recently developed and have the potential to manage malnutrition, with a special emphasis on MAM. The paper will also encourage potential future developments and open up promising avenues in supplementary foods using different techniques and indigenous ingredients of high nutritional value.

Materials and Methods

This review searched the articles by keywords (moderate acute malnutrition, acute malnutrition, ready-to-use supplementary foods, MAM intervention, indigenous RUSF and supplementary foods) and title (n = 323), after which the duplicates were removed (n = 161).

Furthermore, the abstracts of the remaining papers were read and screened (162) from 2016 to 2024 to include recent advances in the field of AM; thereby, the papers were excluded based on the eligibility criteria (Fig. 1). This narrative review aimed to map the domain of study foods. The study included foods that were either conventional (already recommended to manage AM) or newly developed (had potential to manage AM, particularly MAM). The newly developed food products will provide insight into forthcoming research in the field of public health aimed at managing AM. The total number of papers that were finally included in this review are 20 (Fig. 1).

Results and Discussion

Study foods

Ready-to-use food (RUF) is crucial in managing acute malnutrition (AM). Conventional RUF is efficient but costly because it is made using expensive ingredients and supplied globally by a limited number of providers (33). To develop RUF optimized for cost-effectiveness, enhanced nutritional content, higher acceptability and offer high-quality protein while preserving required nutritional requirements by utilizing indigenous crops.

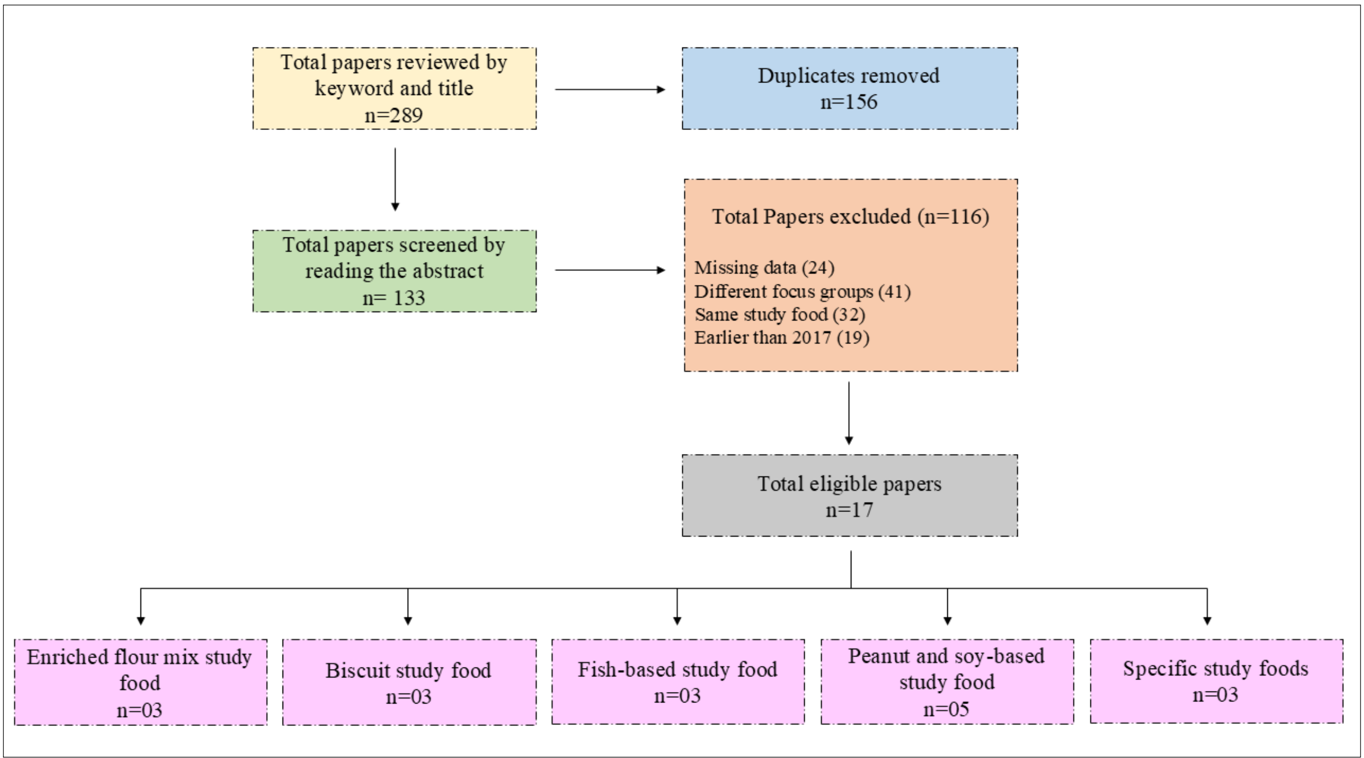

Fig. 1. Study flowchart showing the stages of papers screening and the final number of papers included in this review.

As an alternative to costly protein sources from animals, it is essential to produce supplemental foods for vulnerable populations using readily accessible, high-quality raw ingredients sourced within the country (34). Therefore, the developed products have been grouped under a commodity to understand better the role of certain ingredients in producing a category of supplemental foods.

Development of enriched flour mix

The value of locally available foods in the recovery of malnourished children remains underappreciated (25). Therefore, the development of RUSF has recently emphasized local crops, addressing concerns about food security, sustainability and food autonomy (35). Clinical indicators of infection may be severe in children who are malnourished; therefore, a variety of probiotics and prebiotics can be used to modify and improve the microbiota of malnourished children. Research assessed the effect of malted flour on MAM children (6-24 months) in African countries (36). The flour was produced in two forms (with prebiotics and without prebiotics). The main composition of the flour was wheat (62.4 % without prebiotic and 60.9 % in prebiotic), soy (20.8 % without prebiotic and 20.3 % in prebiotic), 8 % sugar, 7 % dry milk and 1.3 % vitamins. Prebiotic (2 % inulin) was added to the prebiotic-enriched flour. The nutritive value of the two flours is represented in Table 1.

Resaerch indicated that four foods into the intervention: CSB + + [a refined mixture of cereal, legume, milk, sugar, soy oil, dry skim milk powder (SMP), maize flour, dehulled soybean flour and a micronutrient premix (MNP)], misola (a locally made cereal-legume mix fortified with MNP comprises 60 % millet/maize flour, 20 % soy flour, 10 % peanut flour, MNP and amylase powder), local millet flour mix (made of cereal-legume flour with oil fortified with vitamin A and MNP) and RUSF (conventional paste) (37). The results indicated that MAM Malian children supplemented with RUSF showed higher increases in body weight and WLZ compared to using a locally produced blend (Table 2). Another intervention research explored the efficacy of a locally developed enriched flour against the standard plumpy' sup RUSF (100 g) (38). Indigenous ingredients, including sorghum, peanuts, soy, sugar and salt, were used to make the enriched flour. Each child in the study received a 250 g sachet of food daily. The results showed a higher weight gain in the children who were given enriched flour. When using locally made flours, the outcomes are better than when using Plumpy' Sup. However, both foods improved the weight status and decreased the percentage of MAM in children aged 6 to 59 months (Table 2). Additionally, the mix of flours made from indigenous ingredients can serve as an alternative for managing MAM.

Development of biscuits

Bakery items are considered high-energy foods and are simple to make, easy to distribute and fortify and have an extended shelf life. RUSF biscuits are easy to prepare and, by national specifications, encourage essential food diversification and the adoption of underutilised local crops. Additionally, because biscuits are the most beloved by children, they can help battle malnutrition across vulnerable groups. In cases of nutritional inadequacies or limited access to basic amenities, RUSF biscuits are well-established as supplements for emergency feeding programs. This is due to the convenience with which ingredients rich in protein and micronutrient premixes can be incorporated into the recipe. The general mechanism of RUSF biscuits includes combining raw ingredients with additional components to create the RUSF biscuit recipe. In each recipe, the dry ingredients were first combined until a uniform consistency was achieved. The dough was then made when the wet materials were incorporated. After the dough was shaped and cut, it was baked at the ideal temperature and duration in an electric oven.

Reserch developed quality protein maize (QPM)-based biscuits for their dietary supplementation of 60 malnourished children aged 4-6 years (39). A control was made of 100 % wheat flour and the developed biscuits were made of 100 % biofortified QPM. The nutritional analysis revealed an increased protein digestibility (PD) in the QPM biscuits (81.9 %) compared to the control (78.8 %). The study concluded that the nutritional composition (Table 1) of QPM-based biscuits was superior to the wheat biscuits. The supplementation of QPM biscuits also helped reduce the incidence of malnutrition in children (Table 2). The results of this study indicated that a range of supplementary biscuits might be developed and proposed for use in nutrition initiatives to improve the nutritional status of malnourished children.

Resaerch developed two RUSF biscuits (taro-peanut and taro-peanut/mungbean) made from locally available crops (35). Both biscuits included constant ingredients of 6 g wheat flour, 5 g red rice, 18 g sugar powder, 19 g chicken egg yolk, 5 g mungbean powder (only in taro-peanut/mungbean), 5 g banana powder (only in taro-peanut) and 7 mL palm oil (in both the biscuits). The varied ingredients included 6 g and 8 g taro powder, 14 g and 16 g peanut, 14 g and 12 g whole milk powder and 5 g and 4 g maize powder in taro-peanut and taro -peanut/mungbean RUSF biscuits, respectively. The developed biscuits were nutrient-dense (Table 1).

To meet children's 30 % daily protein needs, scientists developed a cost-effective biscuit of high nutritional value (Table 1). As one of the biggest obstacles to RUSF and RUTF accessibility in low-income countries is their expense (10), this development is particularly significant. Not only that, but its traits deviate from the general population's dietary preferences, which makes rejection more likely. The developed RUSF biscuits (Burundi and DR Congo) formulated with different proportions of local ingredients [whole chicken eggs (20 g and 22 g), raw soy flour (13 g and 10 g), niebe flour (10 g and 15 g), peanut flour (16 g and 20 g), rice flour (10 g in both), wheat flour (8 g in Burundi only), brown sugar (15 g in both) and palm oil (6 g in both)]. The shelf-life study revealed that biscuits had a shelf life of 35 days at 30 °C when stored in a basic polyethene plastic bag for up to 35 days.

Development of fish-based products

Fish is an excellent source of protein due to its high quality. Protein, vitamins, amino acids and micronutrients are all found in abundance in fish, which have positive effects on health. Docosahexaenoic acid and eicosapentaenoic acid are long-chain omega-3 fatty acids that are abundant in fish and are potentially good for cardiovascular health. DHA is also necessary for healthy neurological growth and function, as the brain depends on DHA from plasma; a lack of it affects how well vision, cognition and behaviour function. There is also a correlation between a lower risk of Alzheimer's disease with consuming fish.

Table 1. Nutritive value of the study foods

Study food	Nutritive value per 100 g				Others specific parameter	References
	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)		
RUSF-1,	423.37	13.28	11.34	66.23	PER: 12.75, 12.72, 12.70, 9.12 FER: 23.69, 24.11, 24.53, 26.13	(48)
RUSF-2,	424.61	13.30	11.58	66.01		
RUSF-3 and	425.84	13.31	11.81	65.79		
OCG	319.31	7.17	9.44	78.92		
RUSF biscuit Burundi and	-	17.81	19.69	33.00	Protein digestibility: 91.72, 92.01	(10)
RUSF biscuit DRYCongo		16.77	20.06	29.11		
OFSP-CF1 and	416.42	19.82	13.15	54.69	Crude fiber: 3.07, 3.31	(49)
OFSP-CF2	415.99	21.08	13.32	52.94		
WSC1 + WPC,	394.60	19.0	8.4	60.8	Iron (mg): 15.2, 15.9, 15.2, 16.3, 15.6, 15.6, 8.2	(28)
WSC2 + WPC,	396.50	19.7	8.8	59.6		
RSC + WPC,	397.10	19.5	8.5	60.7		
WSC1 + SPI,	395.10	19.2	8.7	59.9		
WSS + WPC,	392.19	19.4	8.0	60.7		
CSB14 + WPC and	392.40	19.3	7.7	61.1		
CSB +	361.64	14.7	4.9	64.7		
Peanut/milk RUF,	402.00	17.6	24.7	-	Vitamin C (mg): 0.2, 14 and 0 Iron (mg): 2.5, 1.6 and 3.9	(42)
Peanut/cowpea RUF and	416.00	14.5	28.9			
Fortified porridge	412	11.9	5.5			
NEWSUP and	1322 kJ	18.1	18.6	19.5	Iron (mg): 19.7, 4.7 Vitamin C (mg): 150, 36.5	(29)
FBF	1322 kJ	5.2	15.0	25.7		
T-P RUSF biscuit and	529.7	14.4	-	-	Iron (mg): 3.6, 4.1 Calcium (mg): 187.3, 186.0	(35)
T-P/M RUSF biscuit	533.0	14.5				
100 % QPM biscuit and	453	8.1	-	-	IVPD: 81.9 %, 78.8 %	(39)
100 % wheat control biscuit	468	6.7				
Prebiotic flour	420	15	9	66	Iron: 23.2 mg Vitamin C: 60 mg	(36)
NumTrey-RUSF	484	13.1	24.4	51.6	Iron: 5.6 mg Vitamin C: 37.4	(27)

RUSF: ready-to-use supplementary food; OCG: oligosaccharide control group; OFSP-CF: orange-fleshed sweet potato complimentary feed; kJ: kilojoules; WSC1 + WPC: white sorghum-cowpea 1 with whey protein concentrate; WSC2 + WPC: white sorghum-cowpea 2 with whey protein concentrate; RSC + WPC: Red sorghum-cowpea with whey protein concentrate; WSC1 + SPI: white sorghum-cowpea 1 with soy protein isolate; WSS + WPC: white-sorghum soya with whey protein concentrate; CSB14 + WPC: corm soy blend 14 with whey protein concentrate; CSB + : corn soy blend plus; NEWSUP: new supplement; FBF: fortified blended food; T-P: taro-peanut; T-P/M: taro-peanut/mungbean; QPM: quality protein maize; PER: protein energy ratio; FER: fat energy ratio; IVPD: *in-vitro* protein digestibility; RUF: ready-to-use food

Table 2. A detailed view of the studies reflecting the key findings of the studies included

Locale, age group and duration	Study design	Inclusion/exclusion and discharge criterion	Feed and sample size	Key findings	References
Burkina Faso, 6-23 months, 12 weeks	Randomized 2 × 2 × 3 factorial trial	-Inclusion: WHZ between -2 and -3, (MUAC) of 115-125 mm -Discharge: 12 weeks	CSB and LNS (n=1609 MAM for both)	Change in Hemoglobin (g/L): From 100±16 to 107±14 for n=1546 Anaemia: Before supplementation (n=1555), 469 children were anaemic and after supplementation (n=1511), the number reduced to 293	(43)
Bangladesh, 12-18 months, 3 months	RCT	-Inclusion: WLZ score < -2 to -3 without bilateral pedal edema -Discharge: 3 months	MDCF-2 (shelf stable with green banana powder): n=62 MAM at baseline and n=59 MAM at endline RUSF (n=62 MAM at baseline and n=59 MAM at endline)	Weight (kg) for MDCF-2 at baseline and end line: 7.32±0.67 and 7.99±0.77 Weight (kg) for RUSF at baseline and end line: 7.28±0.64 and 8.10± Height (cm) for MDCF-2 at baseline and end-line: 72.97±3.53 and 76.32±3.2 Height (cm) for RUSF at baseline and end-line: 73.06±3.17 and 76.0±3.4 WLZ score for MDCF-2 at baseline and end-line: -2.31±0.29 and -1.88±0.56 WLZ score for RUSF at baseline and end-line: -2.40±0.27 and -2.13±0.62	(50, 51)
Mali, 6-35 months, 12 weeks	Community-based cluster randomized trial	-Inclusion: WLZ < −2 and ≥ −3, or MUAC and Mali's national norms (WLZ <80th percentile and ≥70th percentile or MUAC <12.0 cm and ≥11.0 cm -Discharge: WHZ ≥ −2 and a MUAC ≥12.5 cm	RUSF (n=64 MAM) CSB + + (n=85 MAM) MI (n=82 MAM) LMF (n=85 MAM)	Change in length (cm): 3.38; 3.33; 2.52; 2.94 Change in body weight (kg): 1.43; 1.03; 0.84; 1.24 Change in WLZ: 1.23; 0.54; 0.49; 0.99 Change in MUAC (cm): 1.17; 0.87; 0.57; 1.24	(37)
Tanzania, 6-23 months, 20 weeks	RCT	-Inclusion: hemoglobin <10.3 mg/dL, WHZ >-3 -Discharge: A full 20 weeks study was carried out and results were interpreted	No feed (n=124) WSC2 (n=133) CSB14 (n=157) CSB + (n=112) RSC (n=146) WSC1 (n=136) WSS (n=122)	Change in hemoglobin (g/dL): 0.5; 1.0; 1.3; 0.8; 1.1; 1.1; 1.1 Change in weight (kg): 1.0; 1.3; 1.1; 1.0; 1.1; 1.3; 1.1 Change in height (cm): 3.6; 4.3; 4.2; 3.9; 4.4; 4.1; 3.9	(44)
Tanzania, 24-53 months rats, 20 weeks			No feed (n=112) WSC2 (n=122) CSB14 (n=125) CSB + (n=117) RSC (n=123) WSC1 (n=112) WSS (n=131)	Change in hemoglobin (g/dL): 1.2; 11; 1.2; 0.7; 0.9; 0.9; 1.1 Change in weight (kg): 1.0; 1.1; 0.7; 1.1; 0.8; 0.9; 0.7 Change in height (cm): 2.9; 3.8; 3.4; 2.5; 3.5; 3.4	
Guinea-Bissau, 15 months, 23 weeks	RCT	-Inclusion: 15 months-7 years, SAM excluded -Discharge: 23 weeks	NEWSUP (n=157) FBF (n=141)	NEWSUP vs. FBF (ITP) as adjusted mean difference-WAZ score: -0.16, HAZ score: -0.01, haemoglobin concentrations in children with anaemia: 0.40 g/Dl	(29)
Guinea-Bissau, 4-7 years, 23 weeks			NEWSUP (n=202) FBF (n=207)	NEWSUP vs. FBF (ITP) as adjusted mean difference: WAZ score: 0.01, HAZ score: 0.04, haemoglobin concentrations in children with anaemia: 0.24 g/dL	
Chad, 6-59 months, 4 weeks	Randomized comparative study	-Inclusion: WHZ between -2 and -3 -Discharge: 4 weeks time period	RUSF Plumpy' sup (n=40 MAM) Locally enriched flour (n=40 MAM)	Average weight gain in RUSF and enriched flour: 1100 g and 400 g WHZ score at baseline and end-line for RUSF and enriched flour: from -2.42 to -0.86 and from -2.38 to -1.67	(38)
Benin, 6-59 months, 12 days	Cross-over design study	-Inclusion: uncomplicated MAM -Discharge: standard minimum weight gain of 200 g	Multi-ingredient flour (FARIFORTI): (n=289 MAM) Additionally, three locally produced complementary foods were given alternately.	WAZ and HAZ at baseline and end-line: -2.43; -2.12, -2.32; -1.18 and -2.29; -1.61 (prevalence of acute malnutrition did not decrease) Average weight gain: 425.35±18.91 g Average daily weight gain/child: 35.45 g/day	(45)
Africa, 6-24 months, 12 weeks	Open-label, RCT	-Inclusion: MUAC (between 115-130 mm), WHZ (between -3 and -2) - Discharge: WHZ (≥-1.5)	Group 1 control: malted milk flour with antiparasitic (n=297) Group 2: malted milk flour, antiparasitic and azithromycin (n=290) Group 3: malted milk flour, antiparasitic and inulin/FOS included in flour (n=294)	WHZ score -1.5 for group 1,2 and 3 (n, %): 123,41.4 %; 132,45.5 %; 135,45.9 % WHZ score ≥-2 (n, %): 164,55.2 %; 194,66.9 %; 194,66.0 %;	(36, 52)

CBS: corn-soy blend, LNS: lipid-based nutrient supplement, RUSF: ready-to-use supplementary food, MDCF: microbiota-directed complementary food, SAM: severe acute malnutrition, n: number of participants, MUAC: mid-upper arm circumference, MAM: moderate acute malnutrition, MI: misola, LMF: locally millet flours mix, WLZ: weight-for-length z score, WSC2: white sorghum-cowpea 2, WSC2: white sorghum-cowpea 1, WSS: sorghum-soy blend, CSB14: corn-soy blend, RSC: red sorghum-cowpea, WHZ: weight-for height, NEWSUP: new supplement, FBF: fortified blended food; vs.: versus, ITP: intention-to-treat, WAZ: weight-for-age z, HAZ: height-for-age z, RCT: randomized control trial, FOS: fructooligosaccharide

Researchers in recent times have also included fish as the source of primary protein in supplementary foods; one such ready-to-use dietary fish powder was developed for malnourished children in Bangladesh (40). In this research, fish powder was produced from six small Indigenous fishes (*G. chapra, C. nama, N. atherinoides, P. sophore, A. mola and C. soborna*) of which the protein content ranged from 57.33 % to 65.26 %. In contrast, the energy content ranged from 308.33 kcal to 443.00 kcal. Fish powder holds great potential as a nutritional product, offering the capacity to combat malnutrition while guaranteeing safety and quality for human use.

A two-week, randomized experiment without blinding was carried out on 95 children between the ages of 9 and 23 months (41). The acceptance of CSB + + and MNP mixed with borbor was compared to that of locally developed RUSF (stuffed wafer snack or snack mixed into borbor, which is white rice porridge). The original RUSF paste was transformed into a popular Cambodian delicacy called a wafer (inner diameter: 0.5 cm, length: 8.5-9 cm), which was filled with RUSF paste and coconut powder to mask the fishy flavour. Over 12 days, participants at four different locations consumed the three foods on three separate days. Even though participants ate more MNP-borbor, RUSF offered two to three times more calories and caretakers regarded it as the best snack.

Another fish-based RUSF (NumTrey) was developed in Cambodia to reduce the cost and match local taste preferences (27). Dried powder (5.9 g) of small fish (fish species: *Rasbora myersi, Paralaubuca carroini, Henicorhynchus siamensis, Cyprinidae and Puntioplites proctozystron*) rich in calcium was chosen to replace milk powder. The developed RUSF paste was stuffed into a crunchy, long, empty wafer. NumTrey-RUSF consisted of mung beans (9.6 g), soybeans (12.2 g), eggs (2.5 g), rice flour (4.2 g), sugar (7.2 g) and coconut (7.2 g). The nutritive value is presented in Table 1.

Development of peanut and soy-based products

Over 20 years, ready-to-use, low-moisture peanut pastes have revolutionised therapeutic and supplemental feeding for undernourished children, leading to faster recovery outcomes. They offer a structure to food that can accommodate many nutrients due to their strong taste, rendering them nutrient-dense (42). The research indicated that included the use of two RUFs: peanut/milk (36.7 g peanut, 10.3 g palm oil, 9.1 g sugar, 8.0 g maize and 14.9 g cowpea) and peanut/chickpea (28.7 g peanut, 10.3 g palm oil, 9.1 g sugar, 8.0 g cowpea and 22.9 g SMP). Another food included in the study was fortified millet porridge, which was locally produced by boiling millet powder in water for 35 min. The nutritive value of the three products is presented in Table 1. Out of the 871 individuals who were registered and randomized, 292 got PC-RUF, 297 got FP and 282 got PM-RUF. The trial demonstrated that ready-to-use school food, produced with peanuts and milk, enhanced fluid cognition following a year of feeding compared to FP among school children aged 5-12 years in the Mion District of northern Ghana. Of the 574 participants who received a daily ration of peanuts, no adverse effects were observed, including hives, eczematous rashes, or anaphylactic signs or symptoms.

Research showed an intervention to assess the status of anaemia in children in Burkina Faso, which included various food products of two food matrixes [lipid-based nutrient supplement (LNS) and CSB]. The difference was in the quality of soy [dehulled soy (DS) or soy isolate (SI)] and the percentage of SMP (0, 20, 50 % of total protein from milk). The results demonstrated that LNS outperformed CSB in enhancing haemoglobin and iron status. In another study research indicated that five different FBFs (WSC1 + WPC: white sorghum -cowpea 1 with whey protein concentrate, WSC2 + WPC: white sorghum-cowpea 2 with whey protein concentrate, RSC + WPC: Red sorghum-cowpea with whey protein concentrate, WSC1 + SPI: white sorghum-cowpea 1 with soy protein isolate, WSS + WPC: white-sorghum soya with whey protein concentrate, CSB14 + WPC: corn soy blend 14 with whey protein concentrate) were formulated using different ratios of sorghum flour (present in WSC1 + WPC, WSC2 + WPC and RSC + WPC as 24.7g and in WSS + WPC and WSC1 + SPI as 47.6 g and 24.7 g, respectively), cowpea flour (present in WSC1 + WPC, WSC2 + WPC, RSC + WPC and WSC1 + WPC as 38.6 g), soya flour (in proportion 15.7 g and 15.2 g for WSS + WPC and CSB14 + WPC, respectively) corn flour (only present in CSB14 + WPC as 48.1 g), sugar (present in all as constant 15 g), whey protein (9.5g in each except not present in WSC1 + SPI), soya protein (9.5 g only present in WSC1 + SPI), vegetable oil (present in all as 9 mL) and MNP (3.2 g in all formulations) (42). The nutritive value is presented in Table 1. Sorghum and cowpea were incorporated because they have been recommended as substitute crops due to their drought resistance, ease of cultivation and non-genetically engineered nature. These findings suggest that a diverse range of commodities, which are more nutritious than CSB+, can be utilised to develop FBFs that contain superior protein, sugar and oil.

Research developed a new supplement (NEWSUP) for young, undernourished children, rich in omega-3 fatty acids and plant polyphenols (29). The main ingredients used to formulate this high-protein supplement were soy protein isolate, peanut butter, cacao, fortified vegetable oil, honey, fish oil, sugar, matcha, flavourings, MNP and moringa. It was offered as a raw paste, typically containing 98 % of the daily micronutrients that children under four should consume. Each serving of the supplements provided about 1300 kilojoules. In addition to having higher omega-3 fatty acids, total polyphenols, catechin and epicatechin, NEWSUP also had total protein and fat and less carbohydrate, as well as a wider variety and fortification of vital micronutrients. The developed supplement was compared with an existing fortified blended food porridge (results depicted in Table 2), which included super cereal, vegetable oil and sugar as its main ingredients. The nutritive value of the two supplements is presented in Table 1.

Research developed and intervened in a multi-ingredient FARIFORTI flour porridge in Benin on 289 malnourished children for 12 days. 30 % soybean flour, 15 % malted sorghum, 10 % roasted peanuts, 7 % baobab pulp and 2 % dried fried fish made up the 100 g of flour (45). The helpers made the porridge in large batches every day, utilizing 750 g of flour dispersed in 5.30 L of water. The dosage given was 50 g of the prepared porridge. The children and their caregivers expressed great appreciation for the FARIFORTI flour. Research on the impact of local food resources on MAM children found a positive effect on weight gain. Specifically, these resources were found to effectively reduce the incidence of underweight in children under five years old (Table 2).

One of the main barriers to expanding community-based treatment of AM, a crucial child survival approach, is the expense of the currently available standard RUTF. Finding a less expensive substitute is an essential issue for the global public health community. To treat SAM in two groups of children-those aged 6-23 months and those aged 24-59 months, research compared the effectiveness of soya-maize-sorghum RUTF (SMS-RUTF) with that of regular peanut paste-based RUTF (P-RUTF). SMS-RUTF and P-RUTF included a different proportion of soybean, dehulled (38.6 g and 0 g), maize (4.0 g and 0 g), sorghum (10.0 g and 0 g), dried skim milk (0 and 25.0 g), sugar (16.7 g and 27.4 g), peanut paste (0 g and 26 g), palm oil (21.6 g and 20.0 g), linseed oil (2.1 g and 0 g), palm stearin (4 g and 0 g) and vitamin and minerals premix (3.0 g and 1.6 g) (46). The study reported that children who were in the P-RUTF group consumed more RUTF overall. In children aged 6-23 months, the daily intake of SMS-RUTF was 183.2 g/d, while the daily intake of P-RUTF was 207.8 g/d. P-RUTF had a daily intake of 272.7 g/d, while SMS-RUTF had a daily intake of 243.8 g/d for children aged 24 to 59 months. It also observed that SMS-RUTF can be used to treat SAM in children older than 24 months because SMS-RUTF is less expensive to manufacture and uses ingredients that are cultivated locally. Therefore, it would minimise program costs and make it easier to produce RUTF in nations where SAM is a significant issue.

Developments aiming at specific food product

Some researchers have also focused on incorporating other ingredients to develop new food products. One such food product was developed which showed the shelf-stable Microbiota-Directed Complementary Food (MDCF) prototypes to improve the impaired microbiota (47). Two MDCF-2 (25 g and 23.3 g twice daily) were formulated with the same ingredients: chickpea flour, peanut flour, soybean flour, sugar, soybean oil and MNP. The only difference was that of green banana powder and sweet potato, respectively. A version of MDCF-2 (21.7 g twice daily) comprised of separate pre-measured sachets of all the ingredients present in MDCF-2, which were supposed to be mixed before consumption. In this study, the portion size of the feed was adjusted so that each feed provides 250 kcal/day to a child and 70 % of the recommended dietary allowance of micronutrients. The study assessed their impact on MAM children (12-18 months) in Bangladesh, aiming to repair the gut microbiota (results are depicted in Table 2). During the intervention, the MDCF-2 therapy significantly decreased stunting and improved wasting. When comparing the MDCF-2 group to the RUSF group, the researchers found 21 bacterial taxa that had a positive correlation with an improved WLZ score. Increased citrulline concentrations also suggested increased intestinal recuperation and a rise in enterocyte bulk. All these elements are vital for children's healthy growth and development and can improve gut health by supplying essential nutrients; therefore, MDCF-2 exhibited better growth indicators. These findings suggest that incorporating components that support a healthy microbiota host may enhance the efficacy of supplemental meals for undernutrition.

Infants' gut microbiota is constantly evolving and the introduction of supplementary foods marks a significant shift in this regard. Therefore, developed three supplementary foods (RUSF-1, 2 and 3) and compared their effects against the oligosaccharide control group [ingredients: a combination of galacto-oligosaccharide (GOS) and fructo-oligosaccharide (FOS)] on the beneficiaries' gut microbiota (age 6-12 months) (48). The main ingredients in the formulation of RUSF-1, 2 and 3 were different proportions of oat flour, millet flour, corn flour, yolk powder, SMP, sugar, lactose, sunflower and linseed oil, DHA and MNP. The nutritive value for the four products is shown in Table 1. Research developed two complementary foods (CFs) (nutritive value in Table 1) rich in zinc, vitamin A and iron, based on orange-fleshed sweet potato (OFSP), for infants in developing countries (49). The two foods, OFSP-CF1 and OFSP-CF2, included different proportions of OFSP flour (64.57 % and 61.32 %), soybean flour (34.76 % and 37.69 %) and carrot flour (0.68 % and 1.00 %).

Another study conducted on prebiotic GOS was supplemented with RUTF to SAM children (n=58) of 6-59 months (16). GOS is low in mono-sugars and promotes bifdobacterial growth. The primary components of the GOS powder were 69 % prebiotic, 23 % lactose and 5 % monosaccharides such as galactose and glucose. Each day, participants received RUTF and 4 g of prebiotic GOS, diluted with either water or milk. The trial's findings showed that RUTF plus prebiotic was a more effective treatment for SAM children than RUTF alone and that it improved the variety of the gut microbiota in these children. The GOS found in prebiotics has been shown to impact the growth of bifidobacteria positively.

In another intervention conducted, research focused on combating protein-energy malnutrition-induced gut disturbances in albino mice. It was observed that *Lactobacillus reuteri* LR6, administered orally as probiotic fermented milk (109 cfu/animal/day) , restored the gut microbiota that had been depleted during malnutrition, thereby improving gut barrier function. The current study thus proposes the development of new avenues for probiotic supplementation as a natural therapeutic aid to recover from malnutrition, in addition to a traditional diet.

Current limitations and future perspectives

A wide variety of supplementary foods offer interesting options for managing acute malnutrition in children. Furthermore, more indigenous supplementary foods must be optimized and tested for efficacy to meet the ends. It was observed that there are very few options in the field of plant-based supplementary foods; therefore, the area must be researched extensively. Shelf-life testing and storage studies also need to be scientifically evaluated to have a better understanding of the developed products. However, not all developed foods were tested for efficacy; hence, the challenge remains with the acceptability, compliance, cost-effectiveness and effectiveness of such products, as they are directly related to the recovery rates in an intervention study. Furthermore, relapse rates must also be studied to see the overall impact of the research and the required period of rehabilitation. Future perspectives include developing and testing indigenous supplementary foods to lower the cost of interventions and further testing their efficacy on the size of sample needed.

Conclusion

The study evaluates recent developments in the field of food research that have the potential to improve the status of MAM children. There was an increasing trend in the development of these foods by incorporating Indigenous crops. Interestingly, different forms of supplementary foods, such as biscuits and wafers, were also studied. The use of pre-and probiotics for improving the gut health of malnourished children is also a significant step, as their gut health is compromised. It has been observed that their incorporation has a positive impact on overall anthropometric indices. Such studies further encourage the development of creative yet highly nutritional supplementary foods and their intervention trials to establish their efficacy.

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Authors' contributions

VP conceptualized the study, developed the methodology, conducted the investigation and contributed to writing both the original and revised drafts of the manuscript. KC was involved in conceptualizing the study, developing the methodology, supervising the research and revised drafts. NKT and HSO revised the final version of manuscript. HY assisted in editing and revising the final version of the manuscript. All authors read and approved the final version of the manuscript.

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