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A Review of Food-Based Intervention Strategies for Improving Micronutrient Status and Health During Childhood

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Abstract

Micronutrient deficiencies, especially those of iron, vitamin A, zinc and iodine are most common around the world, particularly in children and adolescents. These deficiencies can be prevented through nutrition education and consumption of a healthy diet containing diverse foods, as well as food fortification and supplementation. Available evidence has suggested that instead of synthetic supplements, dietary diversification and modification by including micronutrient-rich foods with appropriate food preparation methods to increase bioavailability, is an effective strategy to treat deficiency state. Therefore, a literature search was conducted for studies i) developing nutritious food products and ii) evaluating food intervention effects. Twelve studies described formulation of snacks/recipes using micronutrient-rich foods and proper cooking methods to enhance bioavailability. Twenty-four food-based intervention trials in children (6 months–16 years) reported increase in micronutrient intakes. Of these, 4 studies reported improvements in all growth parameters except one study showing no improvement in height z scores, 6 studies observed positive changes in bone and muscle development, whereas one study found no effect of dairy intervention on bone mass accrual, 6 studies noted increases in biochemical parameters and/or decrease in infections, whereas two showed no change in serum levels, 4 studies noticed improved cognitive/scholastic performance. Thus, available literature indicates that supplementing snacks or small meals with high bioavailable micronutrient contents significantly increases micronutrient intake and help improving growth and development of children. Further research is warranted to devise food-based strategies for improving micronutrient quality of diets to lower the associated health risks.

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Introduction

Micronutrients are vitamins and minerals, essential for a variety of biological functions in the body. Though, their daily dietary requirements are in very small amounts, deficiency in any one micronutrient can cause adverse effects on health such as susceptibility to infections and decreased work capacity. Childhood is marked with physical, mental and sexual development. Nourishing food is vital during this period to prevent malnutrition and attain the growth potential. Particular micronutrients such as iron, iodine, are essential for cognitive development of children while zinc, vitamin A, calcium and vitamin D are associated with linear growth and skeletal development.[1]

Deficiencies of iron, zinc, iodine, calcium and folate in children below 5 years of age, are common contributors to poor growth, intellectual impairment, and increased risk of morbidity and mortality.[2] Zinc deficiency can result in impaired immunity, stunting and poor-cognitive performance in older children (6–16 years). While anaemia in adolescence can cause reduced physical and mental capacity and diminished concentration in work and educational performance, and also poses a major threat to future safe motherhood in girls.[3]

Micronutrient deficiencies in children and adolescents can be caused by insufficient food intakes, lack of animal foods in diet, low bioavailability of minerals from plant-based diets and increased requirements.[4] The adverse effects of micronutrient deficiencies are preventable by a) including variety of micronutrient-rich foods in daily diet and b) enhancing bioavailability of micronutrients through proper food preparation methods. Therefore, food-based interventions aimed towards increasing dietary modification and diversification are promoted as long-term sustainable strategy for prevention and control of micronutrient deficiencies. Greater dietary diversity has been associated with better growth and micronutrient status in children.[5] Many studies have reported development of nutrient-rich recipes using local foods and choosing appropriate food preparation methods such as sprouting, malting, and fermentation, for improving bioavailable micronutrient intakes. Incorporating animal-source foods in the diet has shown to increase availability of vitamin A, iron, zinc and vitamins B2, B12.[6] Food-to-food fortification of staple food with underutilized plant species (UUPS); e.g., maize with grain amaranth, soybean and moringa; sweet potato with cowpea, sorghum, casava with African yam bean etc. has shown to improve multiple micronutrient intakes; magnesium, phosphorous, zinc, potassium, iron and rise in fibre and protein levels in children.[7] The present review evaluates:

i) studies reporting the potential of dietary modification and diversification strategies at the community or household level

ii) the impact of such dietary intervention on mental and physical health during growing age.

Methods

Studies evaluating food-fortification strategies are diverse in design, outcome measures and age groups. Therefore, a non-systematic review method was applied and web-based literature search was conducted in bibliographical databases for studies reporting:

i) development of nutrient-rich foods or snacks

ii) assessing the impact of food-based intervention on growth, cognition and other health parameters in childhood.

Inclusion criteria were studies describing: i) formulation and evaluation of micronutrient-rich food products, ii) impacts of meals/snacks or lifestyle intervention at household/school/community level through randomized controlled trials (RCTs), iii) primary outcomes like micronutrient intakes, anthropometry, body composition, cognitive function, biomarkers of micronutrients, morbidity.

Exclusion criteria were studies reporting: i) effect of food fortification by micronutrient powders/sprinkles, ii) micronutrient supplements/tablets/syrups/soft-gels, biofortification, iii) in adult population, iv) in diseases.

Literature Search

PubMed Central, Google Scholar, Wiley Online Library were searched for identifying studies. The search keywords included; dietary modification, diversification, micronutrient bioavailability, food-based intervention, randomised controlled trials, children, adolescents, micronutrient-rich foods, local food supplements, food fortification, mid-day meals, growth, bone mass, cognition and health. References from key articles, previous reviews, systematic reviews and meta- analyses were also included in the search.

Results

Study Selection

Of the total 106 identified articles, 12 studies describing micronutrient-rich food products and 24 food-based intervention trials that met the inclusion exclusion criteria were included in this review (Figure 1). Data were extracted from full-text articles of the selected studies.

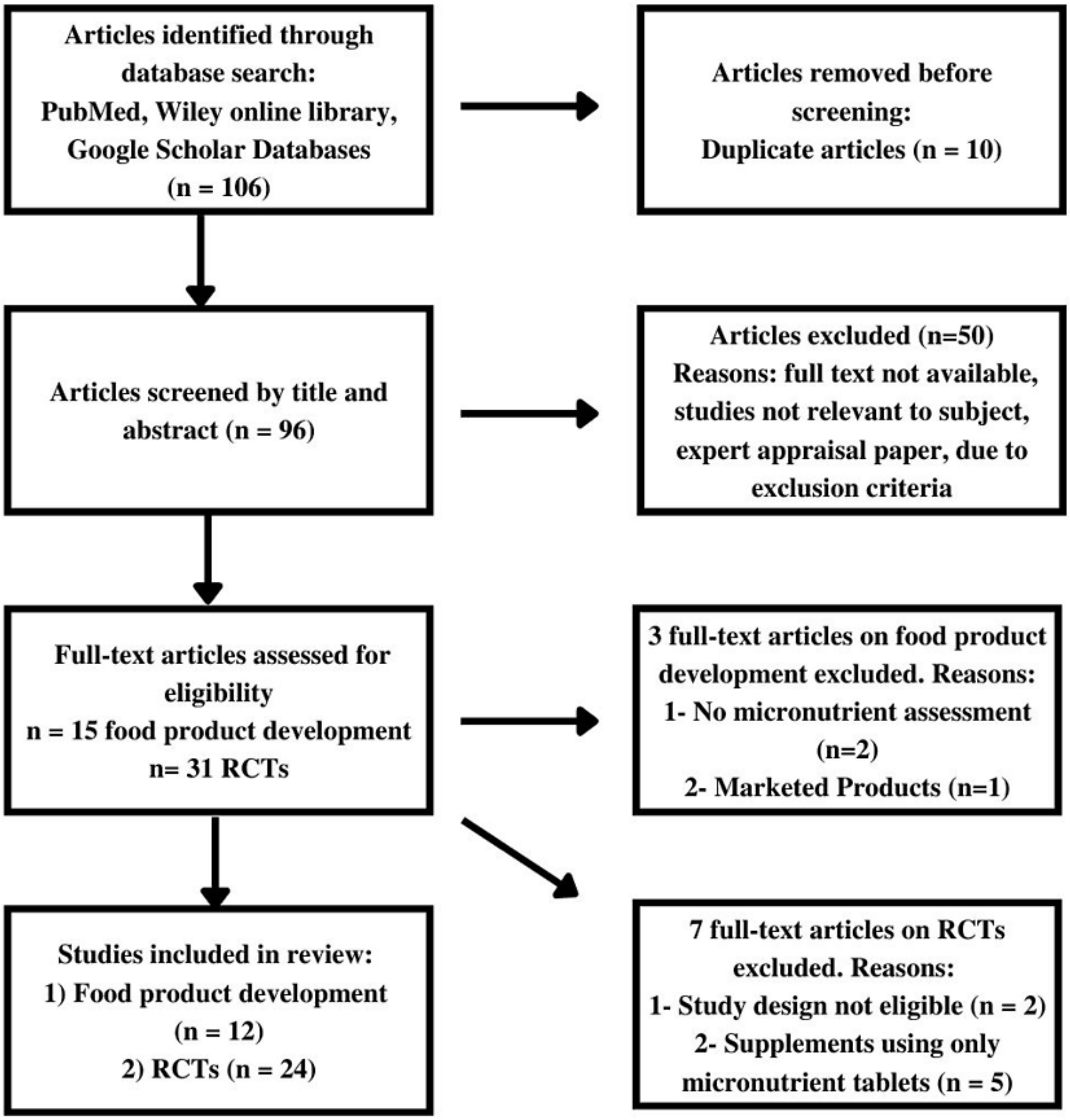

Fig. 1: Flow chart of study selection process

Table 1: Characteristics of studies reporting development of nutrient-rich food products.

Country [ref]	Participants	Food products	Methods	Findings
India [8]	Girls (10-16 yr) n=630	20 cereal-pulse-based recipes using chickpea, soybean, seeds, vegetables, with sprouting/fermentation.	3-day 24-hour diet recall, nutrient intakes, *in-vitro* zinc dialyzability of new recipes vs common meals	New recipes have high contents of zinc, calcium, iron, β-carotene, and vitamin C.
India [11]	-	Meals; cereal+GLV (29), cereal+pulses (12), cereal+other vegetables (16).	Analysed for 8 micronutrients, macronutrients, bioavailability of iron, zinc, copper	Increased bioavailable densities of iron, zinc, copper, 10-fold rise in β-carotene levels, two-fold rise in folate and riboflavin observed in GLV meals than other meals.
India [12]	-	48 meals comprising combinations made from 6 cereals, 4 GLV, 4 other vegetables, 4 pulses.	Nutrient contents, *in-vitro* iron dializability, 31 GLV-based vs 20 non-GLV meals compared.	One GLV-based meal provides > 0.75mg bioavailable iron per 1000 kcal.
India [13]	Type-1 diabetic children and adolescents (5-16 yr) (n=70)	20 healthy snacks rich in calcium, iron, vitamin C, B1, B2, B3, zinc, β-carotene and low carbohydrates developed using spinach, red amaranth, kidney beans, soybean, chickpea, citrus fruits, seeds.	Sensory evaluation, nutrient content of recipes,anthropometry, 3-day diet recall, nutrient intakes.	Five-fold increase in zinc, calcium and iron contents and two-fold increase in vitamin contents (β carotene,vitamin C, vitamin, B1, B2 and B3) in new recipes compared with routine snacks.
Ghana [14]	School-children (4-12 yr) (n=38)	Local dishes devised using dried *M. oleifera* leaves; 1) ofam (baked ripe plantain-roastedmaize cake), 2) beans and gari (roasted cassava grits), 3) waakye (boiled red cowpea and rice); 4) groundnut soup, 5) porridge (composite white maize, groundnut, and white cowpea meal), 6) nkontomire (cocoyam leaves) sauce, jollof rice and 7) apapransa (boiled cowpea and maize flour).	Acceptability, contents of iron, zinc, copper, manganese, β-carotene.	M. oleifera leaf-fortified local dishes well-accepted by children.
India [15]	-	3 types of khichdi (Rice + pulse thick porridge with vegetable) and paratha (flat bread stuffed with filling) formulated using GLV, pearl millet, maize, chickpea which are rich in iron, B vitamins, carotene.	Sensory evaluation by ten semi-trained members.	Overall acceptability for 2 products.
China [16]	110 mothers with children 6 to 23 months.	Six nutritious recipes using local foods providing vitamin A, B1, B2, calcium, iron and zinc.;	24-hour dietary recall, acceptability, compliance, feasibility of 10 recommended recipes	Combination of three recipes for daily three meals satisfies most of the daily recommended

		1) rice porridge with tofu and rape, 2) rice with tomato and pork liver, 3) noodles with egg, tomato, rape, 4) noodles with pork blood, carrots, 5) rice withlean pork, potato, 6) porridge with pumpkin, rape.		nutrients for 6-23 months children.
India [19]	Girls (7–19 yr) (n=236)	Non-dairy-based calcium-rich products (n=14) compared with dairy-based calcium-rich products (n=12).	3-day 24-hour dietary recall, sensory evaluation, macro and micronutrient contents of recipes	Non-dairy and dairy products are on par with respect to calcium contents.
India [20]	Children (2-16 yr) (n=220)	25 recipes developed from millets, soybean, horse-gram, kidney beans, amaranth leaves, cauliflower leaves, seeds, dry coconut, using malting/germination, fermentation.	24-hour dietary recall, calcium, energy and protein contents, calcium intakes, bioavailability	One serving of the recipes provides 42% of the calcium recommended dietary allowance (RDA) in children and 32% in adolescents. Increase of 20% in calcium bioavailability by food processing.
Africa [21]	-	Composite flour of sweet potato, avocado, pear, and Turkey berry with different proportions.	Proximate analysis, contents of iron, calcium, phosphorus, potassium, magnesium, sodium, copper, zinc, vitamin C	Composite flour with 40% sweet potato, 35% avocado pear and 25% Turkey berry was optimal in micronutrients.
Cambodia [22]	Households, mothers, and children under 5 yr of age (n=500)	Homestead food production, increasing household production and consumption of vitamin A–rich fruits and vegetable and small-animal production activities.	1) Household inter-vention (n = 300) 2) Control (n = 200), Consumption of micronutrient-rich foods, illness episodes.	Household production and consumption of micronutrient-rich foods increased, improved maternal and child intake.
Bangla-desh [23]	Children (6-23 months) (n=150)	35 recipes formulated like pumpkin soup, chicken soup, Chirar pulao (Rice + vegetable composite dish), small fish chops, vegetable khichuri (Rice + pulse + vegetable thick porridge), sweet potato halwa (sweet dish), bread, Rice+Chicken+GLV+ oil, Rice+pulse+nuts+ sweet potato+oil, Wheat+Fish+vegetable and White sauce etc.	Contents of 10 nutrients in 30 cooked recipes, acceptability of recipes	28 recipes were most acceptable by both mothers and children.

GLV: Green Leafy Vegetables, yr – years, RDA: Recommended Dietary Allowance

Development of Micronutrient-Rich Food Products

Average dietary intakes of micronutrient-rich foods especially vegetables and fruits, are observed to be low in children and adolescents all over the world.[8,9,10] To improve micronutrient intakes, twelve studies have reported formulation of new recipes as snacks/meals from leafy vegetables, fruits, pulses and millets (Table 1). Emphasis is given to use locally grown foods which are nutritious and are likely to be acceptable by the children.

Habitual diet of adolescent girls was modified by adding sprouted pulses, vegetables to increase bioavailable micronutrient contents of zinc, calcium, iron, β-carotene, and vitamin C.[8] These new recipes were found rich in bioavailable micronutrients. Meals comprising of whole cereals and green leafy vegetables (GLV) were found to improve intakes of zinc, riboflavin, copper, and β-carotene[11] and also sufficient to satisfy daily iron requirement.[12] Snacks without adding sugar/jaggery were made from GLV, beans, fruits and seeds for type-1 diabetic children There was a five-fold increase in calcium, zinc and iron contents as well as two-fold increase in β carotene, vitamin C, vitamin B1, B2, and B3 contents over their usual snacks.[13] Local dishes prepared from GLV, beans, millets and nuts were found to be rich in many micronutrients and acceptable by the young children.[14,15] Meals devised for 6-23 months old Chinese children using rice, tomato, tofu, egg or pork, can meet the recommended dietary allowance (RDA) of most nutrients.[16]

Low dietary calcium intakes (less than half the RDA) are mainly observed in low- and middle-income countries due to limited intake of dairy products.[17,18] To devise recipes/food products rich in calcium contents with high bioavailability,[14] non-dairy food products were developed using millets, soybean, GLV, sesame and methods like malting, fermentation, and sprouting. These were found to be equivalent in calcium contents of 12 dairy-based products prepared using milk, cheese, paneer, cereal, seeds.[19] Furthermore, calcium-rich recipes like multi-millet flatbread, sprout mix, soybean pulao (rice preparation with soybean), amaranth leaves-soy cutlet, were found to increase bioavailable calcium contents satisfying more than one-third of the RDA of children and adolescents.[20]

Local under-utilized food crops in Africa i.e., sweet potato, avocado pear, and turkey berry, were used in different proportions to develop nutrient-dense vegetable flours. The optimal composite flour was found to be the one made up of 40% sweet potato, 35% avocado pear, and 25% turkey berry. The functional properties of the composite flours were better than the control (sweet potato flour). Thus, food-to-food fortification of local flours is feasible and could be an easy and affordable means to improve rural nutrition.[21]

At household level, production and consumption of vitamin A–rich fruits and vegetable and small-animal production activities has a benefit of improving micronutrient status of both mothers and children.[22] For Bangladeshi toddlers, thirty-five recipes were developed from local food items for complementary feeding practices and were found to be acceptable by children.[23]

All these studies indicate the strength of modest changes in selection of foods and proper cooking methods to fulfil daily micronutrient requirements. This approach is of great value in designing complementary feeding and school feeding programs for children as well as for families at household level.

Food-Based Interventions

Twenty-four randomised controlled trials (RCTs) are divided according to effects of dietary changes on children’s growth, body composition, biomarkers and cognitive function (Table 2).

Growth Parameters

As a nutritional supplement, ready-to-use foods (RUFS) were locally developed using rice-lentil or chickpea, to be similar in macro- and micronutrient composition to Plumpy’doz (soy-lipid-based nutrient supplement) for 6-18 months Bangladeshi children.[24] Both RUFS contained sugar, soybean oil and whole-milk powder. Results indicated that RUFS with chickpea and rice-lentil supplementation were equally effective as Plumpy’doz in significant

Table 2: Randomized Controlled Trials evaluating growth, body composition, biomarkers and cognitive function in response to dietary intervention

Country[ref]	Participants	Study design (duration)	Foods/recipes	Intervention groups	Outcomes	Findings
Growth						
Bangladesh[24]	Children 6.2±0.2 months at enrolment (n = 5449)	Cluster-randomized controlled trial (RCT) (1 year)	Two local food products (chickpea, rice-lentil) and a fortified wheat-soy blended food (WSB++)	Nutrition counselling to all 1) Rice-lentil (n=825), 2) Chickpea (n=843), 3) WSB++ (n=851), 4) Control (n=1438), 5) Commercial supplement Plumpy' Doz (n=1492).	Length, weight, Z-scores, 24-hour dietary intake, morbidity in past 3 months, maternal age, education.	Increases in length and weight observed in chickpea, rice-lentil and Plumpy'Doz groups relative to the control.
India[25]	Children, 2.9±0.9 yr, (n=27)	RCT, Self -control (16 weeks)	Four iron-rich snacks cooked in iron pots, Chickpea flour with cauliflower greens/ soybean /cowpea. Sweet snack of garden cress seeds, sesame, sugar, clarified butter.	Four snacks supplemented in a rotating menu for 5 days/week.	Anthropometry, nutrient intake, haemoglobin, serum iron, transferrin	HAZ (height for age Z score and WAZ (weight for age Z score) improved significantly. 7.9 % increase in haemoglobin, serum iron, transferrin.
Iran[26]	Acute and moderately malnourished children, (32.9 ±15.8 months) (n=1288)	Community -based intervention trial (10 months) using multi-stage cluster sampling.	Complementary foods; poultry, red meat, egg, white rice, yogurt, macaroni, oil, lentils, and pinto beans	1) Monthly health and nutrition education; 2) Providing households with locally prepared complementary food.	Anthropometric measurements	Improvement in HAZ, WAZ, and weight for height Z scores (WHZ).
Indonesia [27]	Rural children, (15.8±5.24 months) (n=1090	Quasi-experiment design, (6 weeks)	12 recipes using local foods like red potatoes, pumpkin, kapok bananas, peanuts, carrots, tempeh, milk, chicken and beef.	12 sets of recipes given to children 4 times daily over 6 weeks.	Anthropometric measurements	Significant increase in WHZ, WAZ, and body mass index for age Z score (BAZ) scores but decrease in HAZ scores
India[28]	Adolescents 10-14 yr (n= 243)	RCT (3 months)	In-school millet-based lunch. Recipes idli (steamed millet + lentil cake), khichdi (millet +	1) Millet-legume-based school-lunch (n=160), 2) Control; fortified rice-based school-lunch (n =160),	Height, weight, Z scores, 3-day dietary intake.	Improvement in stunting and BMI in intervention group but not in control.

Country[ref]	Participants	Study design (duration)	Foods/recipes	Intervention groups	Outcomes	Findings
			pulse thick porridge), upma (snack made from millets+ vegetables) /bisibella (spicy vegetable millet preparation) using finger millet, little millet, pearl millet instead of rice.	daily on all school days		
Body composition						
Bangladesh[29]	Children 6.1±0.2 months at enrolment. (n=3592)	Cluster-RCT (One year).	Locally developed lipid-based food supplements compared with fortified Plumpy' Doz, and WSB++	1) Control (no food supplement) (n=934), 2) Plumpy'Doz (n=999), 3) Rice-lentil (n=549), 4) Chickpea (n=546) 5) WSB++ (n=564).	Weight, length measured. Fat mass (FM) and fat free mass (FFM) estimated by equations	FFM was higher in rice-lentil-fed vs controls, WSB++ had no impact on FFM or FM
India[30]	Children 2.7±0.52 yr, (n= 60)	RCT, double-blind (12 months)	Isoenergic cereal-legume sweet snack non-fortified (indigenous calcium 156 mg) vs calcium-fortified snack (405 mg/d)	Snacks for 5 days/week 1) calcium-fortified snack (n=30), 2) non-fortified snack (n=30).Both groups received 30,000 IU of vitamin D3 per month	Height, weight, 3 days diet-recall, total body bone mineral content (TBMC) and bone area, blood iCa, phosphorus, vitamin 25(OH) D	TBMC of fortified-snack group increased by 35% as against 28% in non-fortified snack control group.
Kenya[31]	School-children median age 7.4 yr (n=910)	RCT, (9 months /year for 2 yr)	Three isoenergic supplements; plain githeri (traditional vegetable stew), meat, milk.	1) Meat (N= 195), 2) Milk (N=256), 3) Githeri (N=248), 4) Control, no snack (n=211).	Food intake, height, weight, triceps skin-fold,mid-upper-arm circumference (MUAC); Mid-upper-arm muscle area (MAMA), mid-upper-arm fat area (MAFA).	Meat and Milk groups showed significant gains in MUAC, MAMA than plain githeri & control groups.
Finland[32]	Healthy girls at Tanner stage I-II, 11.2±0.7 yr, (n=195)	Double-blind, RCT (2-yr)	Dairy products (mainly low-fat cheese), or calcium and vitamin D tablets	1) Calcium (1000 mg)+vitamin D3 (200 IU), (n=49) 2) Calcium (1000 mg), (n=49), 3) Cheese (1000 mg calcium), (n= 49),	Anthropometry, menarchal age, physical activity, diet, bone area, bone mass, bone mineral density of whole body, femoral neck,	Adequate calcium intake from food is more beneficial for bone mass accrual than the calcium tablets.

Country[ref]	Participants	Study design (duration)	Foods/recipes	Intervention groups	Outcomes	Findings
				4) placebo (n=48).	total femur, and lumbar spine, lean mass, fat mass. Follow-up visits at 6, 12, 18, and 24 months.	
USA (Indiana)[33]	Healthy-weight or overweight boys & girls 11.8 ± 1.5 yr (n=240)	Randomised controlled parallel arm intervention trial, (18 months)	Extra 3 servings of dairy products (milk, yogurt, cheese) /day equivalent to ~900 mg calcium /day	1) Healthy-weight, control-diet; 2) Overweight, control-diet; 3) Healthy-weight, dairy-supplement; or 4) overweight, dairy supplement	Every 6 months- anthropometry, total-body bone mineral content and density, cortical and trabecular bone mineral density, bone area at the 4% tibia.	No effect of dairy intervention on bone mineral acquisition or body composition.
India[36]	Overweight children 11.3 ±2.9 yr (n=74)	RCT (4 months)	Diet and exercise counselling, healthy recipes demonstration	1) Diet-exercise counselling with multivitamin-zinc supplementation (n= 29) 2) Diet-exercise counselling (n=25), 3) Placebo (n=20)	Anthropometry, biochemical, carotid arterial and lifestyle parameters	Positive effect of multivitamin-zin supplement with lifestyle intervention on the cardiometabolic status of overweight children
Spain[37]	Children, adolescents with abdominal obesity 11.3±2.4 yr (n=107)	RCT (22 months)	Mediterranean style diet with high consumption of fruit, vegetables, whole grains, legumes, nuts, seeds, olive oil, dairy products, fish, poultry; low amount of red meat.	Multidisciplinary lifestyle intervention of eight-week phase with a follow-up. 1)Control, usual care (n = 26) 2) intensive care (n = 81)	Anthropometry, blood pressure, physical activity, dietary intake, blood glucose, insulin, total cholesterol	Intensive care subjects had greater intake of fibre, vitamin B12, C, D. Reduction in BAZ by 0.5 units.
Biomarkers						
Malawi[38]	Stunted children, 30-90 months, (n=281)	Quasi -experi-mental design (6 months)	Diets more diverse, more animal foods and less phytates than control diets.	1) Intervention group- Maize-based diet with soaking, fermentation, germination, with more animal foods, soft-boned fish (n=200),	Knowledge and practices, anthropometry, malaria screening, haemoglobin, hair zinc, 24-h diet recalls, nutrient intakes.	Significantly higher intakes of protein, calcium, zinc (total and available), heme iron, vitamin B12 in the intervention group than the control. Reduced incidence of

Country[ref]	Participants	Study design (duration)	Foods/recipes	Intervention groups	Outcomes	Findings
				2) Control group-unmodified diet (n=81)		anaemia, common infections after intervention.
New Zealand[39]	Children 17.1±2.8 months (n=225)	Randomized intervention trial (20-week)	21 "toddler-friendly" dishes (meatballs and patties), mince dishes, casseroles, stir-fries, meat loaf, lasagna, cottage pie, and liver-bacon spread. 2) Heinz Nurture Toddler Enriched Milk Drink 3) Standard Instantized Whole Milk Powder (Fonterra).	1) Red meat (n = 90), 2) Fortified toddler milk drink (FTMD), with zinc and other micronutrients(n = 45), 3) Nonfortified milk placebo (n = 90).	Hair and serum zinc, length, weight, 3-d weighed food records at baseline, week-4, and week-18, nutrient intakes	Significant increase in dietary zinc intakes in the meat and FTMD groups compared to decrease in the placebo group, but unlikely to improve biochemical zinc status.
China[44]	School-children 7.7±1.0 yr (n=228).	RCT, (10-week)	Wheat flour mixed with spirulina (2 or 4 g) to make noodles/ other foods. Chlorophyll added to wheat flour for control group	1) 4 g spirulina supplement group (n= 78) 2) 2 g spirulina supplement group (n =74) 3) Zero spirulina control group (n= 76), 5 d/week.	Weight, height, haemoglobin, serum retinol, carotenoids, vitamin E	Serum β-carotene, total-body vitamin A stores increased significantly, in both the intervention groups.
South Africa[45]	School-children 8.4±2.2 yr (n=167)	RCT (3 months).	African leafy vegetables (ALV) dish: Amaranthus cruentus (at least 80 %) and Cleome gynandra, Cucurbita maxima or Vigna unguiculata with tomatoes and onion mix (22 %), vegetable oil (3 %), instant gravy powder (5 %).	1) 300 g cooked ALV dish and school-meal starch (n=86) 2) normal school-meal (n=81) 5 days/week	Nutrient contents of ALV, weight, height, haemoglobin, serum ferritin, transferrin, CRP, serum zinc, retinol	ALV didn't improve serum retinol, ferritin, haemoglobin in case of mild deficiencies.
India[46]	Girls 16.4±0.2 yr (n=61)	RCT (AUC-1 day)	1) Malted finger millet pancake and dip with sesame, cumin seeds, coconut, soy,	Interventions: 1) Fermented- malted finger-millet pancake with soy coconut dip (snack; 534 mg	Anthropometry, 24-h recall, nutrient contents, weight, height, serum vitamin D,	Calcium absorption from fermented-malted pancake is on par with standard calcium carbonate supplement.

Country[ref]	Participants	Study design (duration)	Foods/recipes	Intervention groups	Outcomes	Findings
			curry leaves. 2) Pancake fortified with galacto-fructo -oligosaccharide (G-Phos)	calcium/serving); (n=21) 2) Same snack fortified with galacto -fructo oligosac-charides G-FOS (8 g); (n=20) 3) Control; isocaloric snack of rice-flakes with calcium carbonate (540 mg) (n=20).	phosphorus, total Ca, Serum iCa, parathyroid hormone measured at 0, 1, 3, 5, 7, 9 h after the ingestion of snack	G-FOS further enhanced calcium absorption.
Benin[47]	Girls 12-17 yr (n=68)	A quasi-experimental design (22 weeks)	Iron-rich foods (beef, liver, poultry, lentils), increasing enhancers of non heme iron absorption (fish and fruits),decreasing inhibitors of absorption (coffee), soaking, fermentation, avoiding loss of vitamin C.	1) Intervention; 4 weeks of nutrition education with increase in absorbable iron (1.90 mg/day) (n=34), 2) Control (n=34)	Nutrition knowledge questionnaire, 24-hour diet recalls, micronutrient intakes, anthropometry, haemoglobin, total iron binding capacity, serum ferritin, iron, transferrin.	Haemoglobin, serum ferritin significantly higher and prevalence of anaemia lower in the intervention group than in the control group.
India[48]	Type-1 diabetic children, 11.5 ± 3.6 yr. (n=90)	RCT (3 months)	9 recipes: whole-wheat thin crackers with either spinach, fenugreek leaves, mint, or red amaranth leaves; spiced puffed rice with nuts; spiced popped amaranth seeds; sesame seed sweet balls, fruit-vegetable salad.	1) Micronutrient-rich snacks (n = 29). 2) Multi-micronutrient syrup (n= 30); 3) Diabetic controls (n = 31) 4) Healthy controls (n=27)	Anthropometry, fasting total antioxidant status (TAS), HbA1C	Increase in TAS values in diabetic children, but values still lower than in healthy controls. Improvement in HbA1C only in the snacks group.
Kenya[49]	School-children 7.3±1.1 yr (n=902)	RCT (2 years)	Three school-snacks; githeri (stew of maize, beans, greens), with meat, milk or extra oil	1) Plain githeri (n=247), 2) Githeri +Milk or extra oil (n=251), 3) Githeri +Meat (n=192), 4) Control without feeding (n=212)	Anthropometry, food intake, anaemia, upper respiratory tract infections malaria, typhoid.	Intervention groups showed beneficial effects on morbidity status.
Cognitive function						
India[50]	School-	RCT	Zinc-rich snacks using	Three intervention groups:	3-d 24-hr diet recall,	Zinc-rich foods and

Country[ref]	Participants	Study design (duration)	Foods/recipes	Intervention groups	Outcomes	Findings
	girls 12.5±0.85 yr (n=180)	(10 weeks)	millets, sesame, pumpkin seeds, soybean, chick-pea, GLV, prepared with sprouting/fermentation.	1) Ayurvedic zinc -J, 2) Zinc-rich snacks-D, 3) Control-C, for 6 days/week	Haemoglobin, serum ferritin, plasma zinc, cognitive tests, taste acuity	ayurvedic zinc supplement are effective in improving cognitive performance and taste acuity.
Kenya[51]	School-children 7.1± 0•8 yr (n=360)	Cluster-randomised feeding trial (9 months/ year for 2 years)	Three foods; 1) githeri (local plant-based stew) plus meat, 2) githeri plus whole milk; 3) githeri with added oil, 4) control group no intervention feeding.	1) Plain Githeri (n =99), 2) Milk (n =105), 3) Meat (n =67), 4) Control (n= 89).	Nutrient intakes, school test scores	Increased intakes of folate, iron, available iron, energy per body weight, vitamin B12, zinc and riboflavin were significant contributors to the improvement in test scores.
Kenya[52]	School-children 7-8 yr (n= 554)	RCT (24 months).	School-snacks; i) traditional local dish, (githeri) of maize, beans, vegetables; ii) githeri plus milk; iii) githeri plus beef.	Four groups of isoenergic snacks; 1) Vegetarian supplement (githeri), (n=148), 2) Githeri +200 ml cows milk (n=144), 3) Githeri +60 g minced beef (n=134). 4) Control (no food supplement) (n=129)	Weight, 24-h diet recall with mother, school-snack consumption record, nutrient intakes, morbidity recall, four cognitive tests; Raven's Coloured Progressive Matrices (RCPM), test, verbal meaning arithmetic test, digit span (DS)-forward, DS-backward.	Beneficial effects seen; 50% upward shift for iron on RCPM, 20% upward shift for vitamin B12 on DS-forward, 40% upward shift for riboflavin on DS-forward and a 40% shift for zinc on DS-total.
England[53]	School-children 7-9 yr (n=156)	RCT (15-weeks)	Food interventions to improve food choices pupils and nutrient intakes	Modifying food provision and dining environment. 1) Intervention (n = 98) 2) control (n = 58).	Time spent in different work settings, learning -related behaviours during post-lunch-time classes.	Dietary modification can improve learning -related behaviours in the post-lunch period.

African Leafy Vegetables: ALV, Body Mass Index for age Z score: BAZ, Digit Span : DS, Fat Free Mass: FFM, Fat mass : FM, Fortified Toddler Milk Drink : FTMD, Galacto - Fructo Oligosaccharides : G-FOS, Green Leafy Vegetables – GLV, Height for Age Z score : HAZ, Mid Upper Arm Circumference : MUAC Mid Upper Arm Fat Area : MAFA, Mid Upper Arm Muscle Area : MAMA, Randomized Control Trial : RCT, Raven's Coloured Progressive Matrices : RCPM, Total Antioxidant Status : TAS, Total Body Bone Mineral: TBMC, Weight for Age Z score : WAZ, Weight for Height Z score : WHZ, Wheat Soy Blended Food : WSB++, year/years : yr increases in length (of 0.06 cm/month) to 0.09 cm/month) and in weight (of 0.02 kg/month to 0.04 kg/month) relative to the control. Further RUFS significantly reduced linear growth deceleration. The prevalence of stunting at 18 months of age decreased by 4–6% over and above nutrition counselling alone (control group). This underlines the efficacy of local nutrient-rich foods in promoting growth. Promotion of such nutritious, culturally appropriate and acceptable products may be important in food-insecure settings in addition to other strategies for lessening the large burden of childhood stunting in South Asia.

Snacks using iron-rich foods, when cooked in iron pot have additional contents of contaminated iron. A beneficial effect of these snacks on iron status and growth was observed in preschool children, which also indicated that contaminated iron is bioavailable.[25]

A community-based intervention trial was conducted for 10 months in rural and urban malnourished children (6–59 months) from Iran. Complementary foods; i.e., poultry, meat, rice, yogurt, lentils, pinto beans and oil along with nutrition education showed improved growth status of the malnourished children.[26] In Indonesian rural infants and children (5.8–28.7 months), giving local food-based recipes for Complementary feeding also showed improved nutritional status. Further, it is expected to have a positive impact on the knowledge and maternal skills for weaning independently. [27]

Mid-day school-meals in peri-urban region of Karnataka, India, were modified to include finger millet and pearl millet in place of rice along with pigeon pea for better nutritional outcomes. In a 3-months RCT, millet-based mid-day meals were fed to 136 school children, with 107 control children from other schools receiving usual fortified rice-based mid-day meal.[28] The millet-based meals were providing balanced micro and macronutrients than the fortified rice-based meals. Furthermore, a significant improvement in stunting and body mass index (BMI) was observed in the intervention group but not in the control group suggesting the need for proper formulation of school meals.

Body Composition

Bangladeshi children receiving Plumpy'doz and chickpea foods showed higher total fat free mass (FFM) and fat mass (FM) relative to the control group. While the group receiving WSB++̃ (marketed fortified food supplement containing wheat and soy flour, vegetable oil, vitamins, minerals, sugar and milk) showed no impact on FM and FFM. In line with the impact on linear growth, magnitude of increase in FFM was ~2 times greater than the increase in FM. However, the benefits of the intervention did not persist 6 months after the intervention ended.[29] Calcium supplementation through fortified or non-fortified millet-nuts sweet snack for one-year increased bone mass and promoted growth in Indian preschool children indicating the importance of adequate dietary calcium intakes for bone development.[30]

In a feeding intervention trial, for three school terms during 2 years, Kenyan school-children were given three isoenergetic supplements of meat, milk, and plain *githeri*, with control group receiving no supplement. The meat group showed the steepest rates of gain in mid upper arm circumference (MUAC) and mid-upper-arm muscle area (MAMA) over time, the milk group showed the next largest significant MUAC and MAMA gain compared with the plain *githeri* and control groups.[31]

In a 2-y placebo-controlled intervention trial, the effect of calcium-rich food supplements as against calcium and vitamin D tablet on bone parameters were assessed in girls (10-12 years, at Tanner stage I to II). By eligibility criteria, girls having dietary calcium intakes <900 mg/d were assigned to four groups. At the baseline, there were no significant group differences with respect to growth variables, daily nutrient intakes including calcium and hormonal concentrations. Increasing calcium intake from food is found to be more beneficial for bone mass accrual, specifically for cortical thickness of the tibia, than use of tablets containing a similar amount of calcium.[32]

To assess the effect of dairy supplement on bone mass accrual during puberty, an 18-month RCT was conducted in overweight and healthy-weight girls and boys. No significant advantage of extra dairy servings was seen for the change of bone mineral density, bone mass or bone area for the total-body radius, lumbar spine, and total hip. This study suggests that 2 cups milk or the dairy equivalent is adequate for normal bone gain between ages 8 and 16 y years.[33]

Micronutrient deficiencies are linked to a higher risk of overweight and obesity and other debilitating diseases, which can also have long-term consequences including risk of hypertension in adolescents.[34] Antioxidant micronutrients, i.e., vitamin C, E, β-carotene and zinc play a role in hypertension and metabolic syndrome.[35] In a RCT for 4 months, 74 overweight school-children were assigned to 3 intervention groups; diet-exercise counselling with multivitamin-zinc supplementation, diet-exercise counselling and placebo. The study demonstrated a significant reduction of about 3-4% in BMI, waist circumference and body fat%. Moreover, favourable changes were observed in arterial stiffness with multivitamin-zinc supplementation together with lifestyle changes than lifestyle changes alone.[36]

Effect of moderate hypocaloric Mediterranean diet with nutritional education was evaluated in children and adolescents with abdominal obesity. Intake of calcium, iodine and vitamin D were high in the intensive care group with enhanced compliance with recommendations.[37] Both intensive and usual care groups achieved a significant reduction in BMI for age Z score (BAZ), blood glucose and total cholesterol levels.

Biomarkers

In a 6-months intervention trial, variety of foods with high nutritional quality were introduced in rural Malawian households having stunted children (30–90 months old). The changes were made in food selection patterns and modifications in food processing of maize-based diets. Intervention group received significantly more animal-source foods, especially soft-boned fish, and foods having less phytic acid contents. Results indicated that careful selection of locally available foods combined with modifications of household food preparation practices reduced phytate intake, phytate/zinc and phytate/iron molar ratios and increased dietary intakes of protein, calcium, zinc and vitamin B12, even in rural households with very limited resources. Intervention also resulted in reducing anaemia and common infections.[38]

New Zealand toddlers diet was modified to include red meat, or fortified milk or non-fortified milk (placebo). In the meat group zinc intakes significantly increased by 0.8 mg/d (95% CI: 0.5, 1.1) and 0.7 mg/d (95% CI: 0.2, 1.1) in the fortified milk group as against a decrease of -0.5 (95% CI: -0.8, -0.2)[39] However, this modest 14–15% increase in zinc intake was not associated with a corresponding increase in serum or hair zinc concentrations during a 20-week period. Similar results are observed with red meat interventions in America and Kenya and with fortified milk interventions in Chile and Mexico.[40-43] This might have happened because; i) children may not be zinc deficient, ii) both serum and hair zinc indices are insensitive measures of change in zinc status in mild zinc deficiency, and iii) coexisting multiple micronutrient deficiencies. Hence, a proper combination of foods providing multiple micronutrients may be more effective rather than a single food intervention.

Spirulina, a good source of β-carotene, was supplemented in daily meals of school-children in rural China for 5 d/week for 10 weeks. Total-body vitamin A stores of the children increased significantly, with a median increase of 0.160 mmol in children taking 2 g spirulina and of 0.279 mmol in children taking 4 g spirulina.[44]

African leafy vegetables (ALV) were included in the school-meals of south African children. Children were randomly allocated to receive either a 300 g cooked ALV dish with corn starch school-meal or the normal school-meal five times per week for three months. Results indicated that ALV were unable to improve serum retinol, serum ferritin or haemoglobin in case of children having mild deficiencies. Furthermore, despite low zinc status in the study population, ALV consumption did not improve serum zinc concentrations. When adjusted for baseline value, sex, age, school and adherence, no intervention effect of ALV consumption was found on iron, vitamin A and zinc status of children. This might be due to phytate contents in the accompanying corn starch meal, which inhibited absorption of zinc and iron. Daily consumption of mandatory fortified maize-meal porridge and bread, mild deficiencies of iron and vitamin A in the children and relatively short duration of the intervention could have contributed towards the lack of intervention effect.[45] This highlights the need for appropriate preparation methods of ALV to increase micronutrient bioavailability.

Relative calcium absorption of i) calcium-rich millet–legume pancake of fermented and malted flour, and ii) same snack fortified with galacto-fructo-oligosaccharide (G-FOS), was evaluated with a standard calcium carbonate supplement in Indian adolescent girls. The study demonstrated that calcium absorption from pancakes was on par with standard calcium supplement. G-FOS fortification of pancakes increased the fatty acid content of food, which further improved calcium absorption.[46]

Among adolescent girls, 4 weeks of nutrition education combined with an increase in the content and bioavailability of dietary iron for 22 weeks resulted in significantly higher haemoglobin and serum ferritin values in the intervention group than in the control (122 vs.112 g/L, p = .0002 and 32 vs.19 µg/L, p=0.04, respectively). Prevalence of anaemia (32% vs. 85%, p=0.005) and iron-deficiency anaemia (26% vs. 56%, p=0.04) were also significantly lower in the intervention group than in the control group indicating effectiveness of the dietary intervention.[47]

Children with type-1 diabetes were observed to have compromised antioxidant status as compared to healthy controls. To alleviate their antioxidant status, five snacks; whole wheat-GLV thin crackers, puffed rice with nuts; popped amaranth seeds, sesame sweet balls and fruit-vegetable salad were used as diet supplements. These snacks were rich in antioxidant micronutrients; zinc, β-carotene and vitamin C. Results of the three months RCT indicated that micronutrient supplementation helped to improve antioxidant status of diabetic children, but it was still lower than the healthy controls.[48] Though the study duration and sample size are small, these strategies exhibit the potential to alleviate antioxidant micronutrient status in type-1 diabetic children. Furthermore, increasing dietary micronutrient intakes of type-1 diabetic patients may be helpful for avoiding diabetes-related complications.

The school snacks in Kenyan children were devised by augmenting their traditional vegetable dish '*githeri*' (type of stew) with meat or milk, to increase intakes of mainly animal-source protein, available zinc, available iron and vitamin B12. The impact of the school snacks resulted in significant increase in folate, iron, available iron, energy per body weight, vitamin B12, zinc and riboflavin intake. Moreover, there was a decline in upper respiratory infections.[49]

Cognitive Function

In a 10-weeks intervention study, school girls were fed freshly prepared snacks from zinc-rich foods; millets, pumpkin seeds, sesame, soyabean, chick pea, GLV and using soaking, fermentation, and sprouting to enhance zinc bioavailability. Girls were given either snacks (D-group), or ayurvedic zinc tablet (J-group), or no supplement (control), for 6 days/week. Improvement in plasma zinc levels was seen in J group (61.3%) and D group (9%), while cognitive performance improved by 29.6% (J-group) and 24.5% (D-group) and taste recognition threshold for salt by 50% in both intervention groups as against little or no change in the control group.[50]

The school snacks for Kenyan children were devised by augmenting their traditional vegetable dish '*githeri*' with meat or milk, to increase intakes of mainly animal-source protein, available zinc, available iron and vitamin B12. The impact of the school snacks resulted in significantly better test scores in key academic subjects (Arithmetic, English, Kiswahili and Geography) and total test scores compared with the control group.[51]

Two-year longitudinal, randomised controlled feeding intervention study using animal-source foods was carried out in children from twelve primary schools in rural Kenya. The schools were randomised in four groups: 1) control (no food supplement); 2) vegetarian supplement (*githeri*) of maize, beans and vegetables; 3) milk supplement (*githeri* plus 200 ml of whole cow's milk); 4) meat supplement (*githeri* with 60 g minced beef). The response to four cognitive tests; Raven's Coloured Progressive Matrices (RCPM), a verbal meaning test, an arithmetic test and digit span (DS)-forward, DS-backward tests, food intake by 24-h recall and morbidity recall were recorded. Interventions resulted in increased intakes of available iron and zinc, vitamin B12 and riboflavin, which had significant beneficial effects on cognitive performance.[52]

Modification of food provision and dining environment was introduced in secondary school pupils "in England" to read as pupils in England for 15 weeks. Intervention group improved learning-related behaviours in the post-lunch period than the controls.[53]

Conclusion

This review presents scientific evidence regarding impact of food-based interventions with dietary modification/diversification to improve micronutrient status and associated health outcomes in children from 6 months to 16 years. The food products/ recipes developed in the twelve studies were found to increase the micronutrient contents many-fold as compared to the routine diet/snacks. Two studies demonstrated that the new recipes had a greater in vitro dialysability indicating possible increase in absorption. However, the age-groups in these studies range from 6 months 16 years. Therefore, more studies on formulating age-specific recipes/food supplements are necessary.

Twenty-four food-based intervention studies reported positive impact on micronutrient status and various parameters of growth and health of children and adolescents. Among studies assessing effect on growth parameters, four were in young children and one was in adolescents. There was an improvement in HAZ scores except in Indonesian children. This might be the result of difference in study duration, age group and study design.

Positive effects on bone mass content in school-children and on FFM in infants have been observed after food supplementation in six studies but no effect of dairy supplement was seen in one study in spite of longer duration.

Improvement in micronutrient intakes and biomarkers have been observed in six studies. However, no change was reported not in South African and New Zealand children. Whereas cognitive performance was enhanced after food supplements in all the four studies.

For alleviating micronutrient deficiencies, common strategies implemented are short-term supplementation of fortified foods or multivitamin-mineral tablets. However, the present review highlights the need for long-term strategy based on food-based interventions including dietary diversification with life style modifications to improve micronutrient status and health of growing children. One of the limitations of this review is that number of food-based intervention studies are scarce in literature. Therefore, a small and heterogeneous set of studies could be included in the review. More rigorously designed intervention trials with dietary diversification or modification are necessary in vulnerable age groups for sustainable health benefits and functional outcomes. Key pointers for improvement in micronutrient status of children that emerge from the review are;

1. Dietary diversification by improving the nutrition knowledge of mothers/caregivers.
2. Dietary modification by including local micronutrient-rich foods
3. Improving bioavailability of micronutrients of food products/recipes through sprouting/ malting/ fermentation processes.

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Conflicts of Interest

All authors declare no conflicts of interest.

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