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Complementary Feeding Diets Made of Local Foods Can Be Optimized, but Additional Interventions Will Be Needed to Meet Iron and Zinc Requirements in 6- to 23-Month-Old Children in Low- and Middle-Income Countries

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Abstract

Background: The question whether diets composed of local foods can meet recommended nutrient intakes in children aged 6 to 23 months living in low- and middle-income countries is contested.
Objective: To review evidence of studies evaluating whether (1) macro- and micronutrient requirements of children aged 6 to 23 months from low- and middle-income countries are met by the consumption of locally available foods ("observed intake") and (2) nutrient requirements can be met when the use of local foods is optimized, using modeling techniques ("modeled intake").
Methods: Twenty-three articles were included after conducting a systematic literature search. To allow for comparisons between studies, findings of 15 observed intake studies were compared against their contribution to a standardized recommended nutrient intake from complementary foods. For studies with data on intake distribution, %< estimated average requirements were calculated.
Results: Data from the observed intake studies indicate that children aged 6 to 23 months meet requirements of protein, while diets are inadequate in calcium, iron, and zinc. Also for energy, vitamin A, thiamin, riboflavin, niacin, folate, and vitamin C, children did not always fulfill their requirements. Very few studies reported on vitamin B6, B12, and magnesium, and no conclusions can be drawn for these nutrients. When diets are optimized using modeling techniques, most of these nutrient

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requirements can be met, with the exception of iron and zinc and in some settings calcium, folate, and B vitamins.
Conclusion: Our findings suggest that optimizing the use of local foods in diets of children aged 6 to 23 months can improve nutrient intakes; however, additional cost-effective strategies are needed to ensure adequate intakes of iron and zinc.

Keywords
local foods, complementary foods, nutrient requirements, 6- to 23-month-old children, micronutrients

Introduction

Adequate nutrition during infancy and early childhood is fundamental to the development of each child's full human potential. It is well recognized that the period from conception to 2 years of age is a "critical window" for the promotion of optimal growth, health, and development.[1] The World Health Organization (WHO) recommends that after the age of 6 months, breast-feeding should continue until 24 months of age and beyond, whereas energy- and nutrient-dense complementary foods should be introduced to all infants with an emphasis on the use of suitable locally available foods.[2]

The challenge for 6- to 23-month-old children to obtain all of their nutrient requirements from locally available and typically unfortified foods has been discussed previously.[3] The predominantly cereal-based, monotonous diet in low-income countries, resulting in low dietary diversity, low nutrient density, and poor micronutrient bioavailability, is recognized as a main cause.[3] In addition, children aged 6 to 23 months require high amounts of micronutrients to grow and develop, but due to their smaller stomach capacities, they can only consume relatively small volumes of the family diet. However, others have challenged whether special formulated, complementary foods should be consumed at all, recommending a rapid and direct transition to the family-food diet.[4]

We performed a systematic literature search of studies investigating whether locally available foods are currently meeting or have the potential to meet the energy, protein, and micronutrient needs of children aged 6 to 23 months and assessed whether this may differ by age subgroup (ie, 6-8, 9-11, 12-23 months of age). All of the reviewed studies addressed the question whether locally available complementary foods (ie, locally available foods or local foods) can satisfy macro- and/or micronutrient needs of young children. Locally available foods were defined as foods available in the household and/or market and consumed by the child, which may or may not include fortified foods, such as fortified cooking oil or fortified commercial infant foods. Most studies aimed to determine whether current dietary intakes from local complementary foods were adequate (referred to as "observed intakes studies"). Other studies included used modeling techniques to optimize intakes based on available or consumed complementary foods within given certain constraints such as constraints on food amounts or frequency of consumption (referred to as "modeled intake studies").

Methods

Search Strategy

In October 2015, a systematic literature search in the PubMed, Web of Science, and MEDLINE databases was performed using the following search terms: (micronutrient* OR iron OR zinc OR iodine OR vitamin-a OR macronutrient* OR energy OR protein OR fat OR carbohydrate) AND (complement* OR supplement* OR wean*) AND (intake OR consumption OR needs OR requirement) AND (local* OR agricultur* OR traditional* OR household*) AND (infan* OR child*) AND (food* OR diet*) AND ("developing countries" OR "low income countries" OR africa OR asia OR "latin america" OR "south america"). All papers identified by this search were assessed for relevance. Reference sections of the retrieved articles were used to obtain additional articles that were not found by the formal searches.

Study Selection Criteria

Studies focusing on locally available complementary food consumption by children aged 6 to 23 months in Africa, Asia, or Latin America were included. The following references were excluded: (1) studies referring to case reports, commentaries, and in vitro studies; (2) intervention studies focusing on supplementation/supplementary foods or point-of-use or commercial fortification; (3) studies investigating less than 3 micronutrients; (4) studies from before 1998 or studies that used reference values from before 1998, as new guidelines on complementary feeding were published in 1998[5]; and (5) studies not published in the English language. Where relevant, published reports by nongovernmental organizations based on primary data, identified by gray literature search, were included, provided that this information was accessible to the public. Other unpublished data were excluded.

Titles and abstracts of articles retrieved were screened independently by 3 authors (B.B., E.K., and L.B.) to determine whether they might meet the inclusion criteria. Full-text articles were screened if their inclusion or exclusion could not be determined easily by their titles and abstracts. Differences of opinion about suitability for inclusion were resolved by consultation with a fourth reviewer (S.O.).

Two types of studies were identified: (1) studies reporting on dietary intakes from locally available complementary foods as determined by dietary assessment methods in cross-sectional, case–control, cohort or intervention studies (observed intake studies) and (2) studies investigating theoretical dietary intakes based on locally available complementary foods using modeling techniques to optimize intakes within given (costs) constraints (modeled intake studies).

In the observed intake studies included in this review, "locally available foods" were defined as foods available in the household and consumed by the child, which may or may not include fortified foods, including fortified commercial infant foods and fortified cooking oil. In the modeled intake studies, locally available foods were defined as foods available in the market and/or household or as foods typically consumed by the child as assessed from (national representative) food consumption surveys.

Data Handling and Analytical Strategy

Considering the methodological differences to determine adequacy of dietary intakes from locally available complementary foods between the observed and modeled intake studies, their data were analyzed separately.

Observed Intake Studies

The studies included used various methods and reference values to assess dietary adequacy from local complementary foods. From all studies included, the most commonly used method was to compare the mean or median nutrient intakes from complementary foods to the recommended nutrient intakes (RNIs).[6-8] However, it is no longer considered appropriate to assess dietary adequacy by comparing absolute nutrient intakes against the RNI because the prevalence of inadequacy depends on the shape and variation in the usual intake distribution and not on the mean or median intakes.[7] Instead, adequacy of dietary intakes should be evaluated against the estimated average requirements (EARs) by calculating the proportion of the population with intakes below the EAR using the EAR cut-point method. The EAR cut-point method assumes that the proportion of a population with intakes below the EAR for a given nutrient corresponds to the population having an inadequate intake for that nutrient.[9,10]

To allow for comparisons between the observed intake studies and in order to standardize the reporting of findings, we aligned the methods used to assess dietary adequacy of the individual studies as follows: first, the proportion of children at risk of inadequate intakes for specific nutrients was estimated using the EAR cut-point method. The EARs[7,10-16] were corrected for breast-milk intake (EAR-CF) to define the EAR from complementary foods, as follows:

the EARs of protein and micronutrients required from complementary foods were estimated by subtracting the amounts provided by human milk from the EAR for each of the age intervals following the method as described by WHO and Dewey and Brown.[5,17] Using the mean and standard deviation (SD) of nutrient intakes (ie, assuming normal distribution), the area under the curve below the EAR-CF was determined, representing the population proportion at risk of inadequate intakes for a given nutrient.[9] Unfortunately, not all studies reported mean and distribution of intakes, and an EAR has not been established for all nutrients and age-groups, particularly not for children aged 6 to 11 months, and it was therefore not possible to calculate the %<EAR-CF for all studies. In order to compare the findings of all observed intake studies, the estimated nutrient requirements from complementary foods as defined by Lutter and Dewey[18] were used as standardized reference dietary intake (RDI) values. All observed dietary intakes as reported were compared to these standardized reference values. The reported observed dietary intakes from local foods were expressed as percentage of the RNI corrected for mean breast-milk intakes and breast-milk nutrient composition as defined by WHO[5] and Dewey and Brown[17] (%RNI-CF). For iron and zinc, RNIs for diets with medium bioavailability were used. Reference intake values used for all comparisons are presented in Table 1. We did not attempt to meta-analyze the observed intake studies because an average estimate would have masked the heterogeneity in terms of age-groups, geography, sampling, and analytical methods. Thus, the results of the observed intake studies are presented individually.

Modeled Intake Studies

The modeled intake studies modeled theoretical intakes or nutrient densities against recommended intakes or nutrient densities. Six[19-24] of the modeled intake studies used linear programming, a mathematical tool, that can be used among others to formulate optimized complementary feeding diets, which resemble current dietary practices as closely as possible while at the same time ensuring optimal nutrient intakes.[25] Details of the linear programming process and its challenges have been described before.[26] Santika et al,[20] Skau et al,[19] and Fahmida et al[21] used the linear programming software Optifood[25,26] and reported findings based on best-case scenarios (ie, maximizing nutrient content of the diets selecting high nutrient-dense foods) and worst-case scenarios (ie, optimizing nutrient content, selecting foods with the lowest nutrient density). Optimized scenarios (the nutritionally best model, optimizing all nutrient intakes simultaneously) were reported as well. All models were based on frequently consumed foods and take into account constraints such as diet's energy content, food consumption frequency patterns, food portion sizes, and costs. Wu et al[22] created nutritious food combinations using the ProPAN tool. Adrianopoli et al[23] used NutriSurvey as linear modeling tool and optimized intakes using different combinations of food amount constraints. Vita and Dewey[24] used Microsoft Excel as linear modeling tool and modeled scenarios with and without constraints on type of foods consumed (ie, minimum quantity from staple foods and/or minimum consumption from 5 food groups).

Two of the modeled intake studies[27,28] did not use linear programming but modeled observed nutrient densities of best-case scenario diets (ie, diets meeting nutrient adequacy) to meet nutrient and nutrient density requirements of children aged 6 to 23 months using assumptions for energy, protein, and nutrient requirements. The results of the modeled intake studies are presented individually because of the limited number of studies found.

Results

In total, 536 records were identified by PubMed (n = 279), Web of Science (n = 115), and MEDLINE (n = 143) after conducting the systematic search. Since the records retrieved from MEDLINE were mostly duplicates of the records identified by the other 2 databases, only the first 30 MEDLINE records were screened. Thirty-four references were added for review through scanning secondary references ("own search"). In

Table 1. Standardized Reference Values for Dietary Intake Corrected for Breast-Milk Intake Used for Standardization of Results of the Observed Intake Studies.

	6-8 Months				9-11 Months				12-23 Months			
	RNI	RNI-CF[a]	EAR	EAR-CF[b]	RNI	RNI-CF[a]	EAR	EAR-CF[b]	RNI	RNI-CF[a]	EAR	EAR-CF[b]
Energy, kcal/d	615[c]	202	NA	NA	686[c]	307	NA	NA	894[c]	548	NA	NA
Protein, g/d	9.1[d]	2	NA	NA	9.6[d]	3.1	NA	NA	10.9[d]	5	NA	NA
Vitamin A, μgRE/d	400[e]	63	NA	NA	400[e]	92	NA	NA	400[e]	126	286[f]	12
Thiamin, mg/d	0.3[e]	0.2	NA	NA	0.3[e]	0.2	NA	NA	0.5[e]	0.4	0.4[f]	0.3
Riboflavin, mg/d	0.4[e]	0.2	NA	NA	0.4[e]	0.2	NA	NA	0.5[e]	0.3	0.4[f]	0.2
Niacin, mgNE/d	4[e]	3	NA	NA	4[e]	3	NA	NA	6[e]	5	5[f]	4
Vitamin B6, mg/d	0.3[e]	0	NA	NA	0.3[e]	0	NA	NA	0.5[e]	0	0.4[f]	0
Vitamin B12, μg/d	0.7[e]	0.3	0.6[e]	0.2	0.7[e]	0.3	0.6[e]	0.2	0.9[e]	0.4	0.7[f]	0.2
Folate, μg/d	80[e]	48	65[e]	33	80[e]	48	65[e]	33	150[e]	103	120[f]	73
Vitamin C, mg/d	30[e]	5	NA	NA	30[e]	5	NA	NA	30[e]	8	25[f]	3
Calcium, mg/d	400[e]	211	NA	NA	400[e]	228	NA	NA	500[e]	346	417[f]	263
Iron, mg/d[g]	9.3[e]	9.1	6.9[h,i]	6.7	9.3[e]	9.1	6.9[h,i]	6.7	5.8[e]	5.6	3.0[h,i]	2.8
Zinc, mg/d[j]	4.1[e]	3.3	2.5[h]	1.7	4.1[e]	3.4	2.5[h]	1.8	4.1[e]	3.4	3.4[f]	1.3
Magnesium, mg/d	54[e]	30	NA	NA	54[e]	32	NA	NA	60[e]	41	65[h,k]	46

Abbreviations: EAR, estimated average requirement, average daily nutrient intake level estimated to meet the requirements in 50% of the healthy individuals; EAR-CF, EAR corrected for breast-milk intake; RE, retinol equivalents; RNI, recommended nutrient intake, average daily dietary intake level estimated to meet the requirements in almost all (97.5%) healthy individuals; RNI-CF, RNI corrected for mean breast-milk intake; NA, not available (shaded); NE, niacin equivalents.

[a]Estimated needs from complementary foods, RNI corrected for mean breast-milk intake and breast-milk composition as reported by the World Health Organization[5] and Dewey and Brown.[17]

[b]Estimated average requirements from complementary foods, EAR corrected for mean breast-milk intake and breast-milk composition as reported by the World Health Organization[5] and Dewey and Brown.[17]

[c]Dewey and Brown.[17]

[d]World Health Organization.[5]

[e]World Health Organization.[7]

[f]World Health Organization.[10]

[g]Assuming 10% bioavailability.

[h]Institute of Medicine.[12-16]

[i]The EAR for iron has been set by modeling the components of iron requirements estimating the requirement for absorbed iron at the 50% percentile with use of an upper limit of 10% iron absorption according to Institute of Medicine (IOM).[16]

[j]Assuming moderate bioavailability.

[k]The difference between EAR and RNI for magnesium is due to the fact that different references were used to calculate both.

total, 119 articles were selected as being relevant for further review, of which finally 23 articles were included; 15 studies reported observed dietary intakes, whereas 8 studies described modeled intakes. A flowchart describing the study selection process and reasons for exclusion is presented in Figure 1.

Fourteen of the 15 observed intake studies reported absolute dietary intakes from complementary foods per day as median and interquartile range (n = 9) or mean and SD (n = 5). One study reported total dietary intake (mean, SD), that is, intake from breast-milk consumption and complementary foods.[23] In 11 of the observed intake studies,[29-39] all children were (partially) breast-fed, whereas in 3[23,40,41] of the studies, more than 80% of children were breast-fed. For all these studies, nutrient intakes were

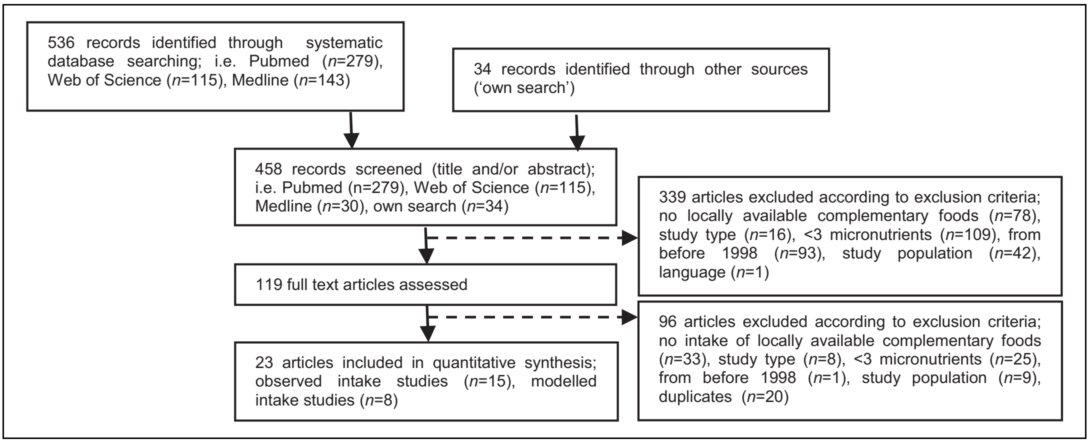

Figure 1. Study selection process.

compared against RNI and EAR corrected for average breast-milk intakes (%RNI-CF and %EAR-CF). In 1 study,[42] 41 infants were reported to be partially breast-fed, whereas 210 infants were non–breast-fed. For this study, the RNI and EAR uncorrected for breast-milk intakes were used for the comparisons. The 15 observed intake studies reported findings for at least one of the following age subgroups: 6 to 8 months (n = 10), 9 to 11 months (n = 12), 6 to 12 months (n = 1), and 12 to 23 months (n = 9). Three of the observed intake studies, 2 from Latin America[32,33] and 1 from South Africa,[40] reported the use of fortified (commercial) infant foods in the study population. The other observed intake studies did not mention any consumption of fortified foods. With regard to the 8 modeled intake studies, only 1 study reported dietary intakes from complementary foods together with the intakes as %RDI,[23] 4 studies reported nutrient intakes as %RNI,[19,20,23,24] 2 studies identified nutrient density gaps,[27,28] and 1 study reported only on problem nutrients defined as <100% RNI in the nutritionally best linear programming model.[21] Table 2 gives an overview of the characteristics of the 23 studies included.

Observed Dietary Intakes From Locally Available Complementary Foods

An overview of the results as reported in the observed intake studies is presented in Table 3. This table includes intakes as %RNI as reported by the investigators, using various methods and reference values to assess dietary adequacy. The calculated %RNI-CF and %<EAR-CF using standardized reference values as described in Table 1 using data from the 15 observed intake studies are presented by age-group in Table 4.

Protein requirements were met with local complementary foods, since the standardized %RNI-CF was close to or above 100% in all studies that evaluated protein. An overview of the calculated %RNI-CF per study and age-group for protein is presented in Figure 2A. In contrast, diets based on local foods were generally not adequate in calcium, iron, and zinc. Figure 2B gives an overview of the calculated %RNI-CF per study and age-group for iron as an illustration of a nutrient for which, in general, inadequate intakes were reported. For the other nutrients investigated, that is, energy, vitamin A, thiamin, riboflavin, niacin, folate, and vitamin C, adequate intakes were reported in some studies but not in others. Figure 2C gives an overview of the calculated %RNI-CF per study and age-group for vitamin A, as an illustration of a nutrient for which the findings on dietary adequacy were inconsistent across studies. Very few studies reported vitamin B6 intakes (1 study, for all age-groups[23]), vitamin B12, and magnesium (1 study for all age-groups,[23] 1 study for 2 age-groups[39]), and no conclusions can be drawn therefore on dietary adequacy for these nutrients based on the observed intake studies.

Table 2. Characteristics of the Included Studies: Observed Intake Studies (n = 15) and Modeled Intake Studies (n = 7).

Author (Year)	Country	Study Design	Population: Age-Group (n)	Study Selection	Dietary Intake Methods	Nutrient Gaps as Reported
Observed intake studies						
Hotz and Gibson (2001)[34]	Malawi	Cross-sectional study	6-8 months (n = 26)	Convenience sample of rural children	Single 24-hour recall	Calcium, iron, zinc
			9-11 months (n = 32)			
			12-23 months (n = 86)			
Paul et al (2011)[30]	Tanzania	Cross-sectional study	6-8 months (n = 28)	Random sample from list of eligible semiurban and rural households	Two nonconsecutive 24-hour recalls	Protein, vitamin A, folate, calcium
	Zimbabwe		9-11 months (n = 48)			Iron, zinc
Faber (2005)[40]	South Africa	Cross-sectional study	6-8 months (n = 138)	Rural children	Single 24-hour recall	Calcium, iron, zinc
			9-11 months (n = 133)			
Paul et al (2012)[31]	Zimbabwe	Intervention study	6-12 months (n = 16)	Random sample from list of eligible rural children	Three 24-hour recalls, 3 interviews, 1 observation	Fat, iron, zinc
Gibson et al (2009)[36]	Ethiopia	Cross-sectional study	6-8 months (n = 17)	Convenience sample of rural children from resource-poor households	1-day weighed food record	Vitamin A, vitamin C, calcium
			9-11 months (n = 20)			
			12-23 months (n = 56)			
Adrianopoli et al(2007)[23]	Tajikistan	Cross-sectional study	6-8 months (n = 12)	Convenience sample of urban and rural children not from the poorest and most isolated families	Single 24-hour recall, food frequency questionnaire	NR
			9-11 months (n = 11)			
			12-23 months (n = 9)			
Lander et al (2010)[41]	Mongolia	Cross-sectional study	6-8 months (n = 26)	Random sample from list of eligible urban and rural children	Single 24-hour recall	Iron, zinc, vitamin C, vitamin A, calcium
			9-11 months (n = 29)			
			12-23 months (n = 73)			
Kimmons et al (2005)[39]	Bangladesh	Cross-sectional study	6-8 months (n = 61)	Convenience sample of rural children	Combination of 12-hour food record with 12-hour recall	Iron, zinc, vitamin D, vitamin B6
			9-12 months (n = 74)			
Campos et al (2010)[32]	Guatemala	Cross-sectional study	6-8 months (n = 34)	Convenience sample of rural children from poor households	Three nonconsecutive 24-hour recalls	Calcium, iron, zinc
			9-11 months (n = 30)			
Hernández et al (2011)[33]	Guatemala	Cross-sectional study	6-8 months (n = 40)	Convenience sample of urban children	Three nonconsecutive 24-hour recalls	Calcium, iron, zinc
			9-11 months (n = 24)			

(continued)

Table 2. (continued)

Author (Year)	Country	Study Design	Population: Age-Group (n)	Study Selection	Dietary Intake Methods	Nutrient Gaps as Reported
Roche et al (2011)[38]	Peru	Case–control study	6-8 months (n = 5) 9-11 months (n = 4) 12-23 months (n = 15)	Convenience sample of children living in the Amazonas district	Two nonconsecutive 24-hour recalls	Vitamin A (only at age 9-11 months), calcium, iron, zinc
Hotz and Gibson (2004)[35]	Malawi	Intervention study	9-11 months (n = 16) 12-23 months (n = 55)	Convenience sample of rural children	Single 24-hour recall	Vitamin A (only at age 9-11 months), iron, zinc
Perlas et al (2004)[37]	Philippines	Cohort study	9-11 months (n = 1794) 12-23 months (n = 1543)	Urban and rural children from poor households	Single 24-hour recall, questions on food pattern	Energy, vitamin A, vitamin C, thiamin, riboflavin, niacin
Anderson et al (2008)[42]	Cambodia	Cross-sectional study	12-23 months (n = 22)	Convenience sample of children living in poor urban villages	Single 24-hour recall	Calcium, iron, zinc
Baye et al (2013)[29]	Ethiopia	Cross-sectional study	12-23 months (n = 62)	Partly random sample from list of eligible rural children	Two nonconsecutive 24-hour recalls	Energy, calcium, zinc, vitamin A, vitamin C
Modeled intake studies						
Skau et al (2013)[19]	Cambodia	Linear modeling study	6-8 months (n = 35) 9-11 months (n = 43)	Random sampling	24-hour recall. Win-food (local CF) group included	Thiamin, riboflavin, niacin, iron, zinc, vitamin B-6 (at age 6-8 months), folate
Vitta and Dewey (2012)[24]	Ethiopia, Vietnam, Bangladesh	Linear modeling study	6-8 months (n = NR) 9-11 months (n = NR)	NR	Three scenarios based on unfortified CF	Vitamin B6, iron, zinc
Adrianopoli et al (2007)[23]	Tajikistan	Linear modeling study	6-8 months (n = 12) 9-11 months (n = 15) 12-23 months (n = 16)	Urban and rural children	24-hour recall, food frequency questionnaire	Thiamin, folate, calcium, iron, zinc
Vossenaar and Solomons (2012)[27]	Guatemala	Linear modeling study	6-23 months (n = NR)	Children from urban and rural poor households	Nutrient density intake compared to critical nutrient density	Calcium, iron, zinc
Vossenaar et al (2012)[28]	Guatemala	Linear modeling study	6-8 months (n = 128) 9-11 months (n = NR)	Children from urban and rural, low-income households	Nutrient density intake compared to critical nutrient density	Calcium, iron, zinc

(continued)

Table 2. (continued)

Author (Year)	Country	Study Design	Population: Age-Group (n)	Study Selection	Dietary Intake Methods	Nutrient Gaps as Reported
Santika et al (2009)[20]	Indonesia	Linear modeling study	9-11 months (n = 100)	Children from periurban villages	12-hour weighed diet record, 12-hour recall	Niacin, calcium, iron, zinc
Wu et al (2013)[22]	China	Linear modeling study	12-23 months (n = 110)	Convenience sample of rural children	24-hour recall, local food market survey, key food list and combinations, recipes	Energy, fat, thiamin, iron, zinc
Fahmida et al (2014)[21]	Indonesia	Linear modeling study	6-8 months (n = 2768)	Analyses based on 4 different studies: national representative data from the National Basic Health Survey	Analyses based on 4 different studies combined with local market surveys: study 1: single 24-hour recall	Calcium, iron, zinc, niacin, folate
			9-11 months (n = 3394)	Children 9-11 months from low socioeconomic status households; children 9-23 months from low socioeconomic status households	Study 2, 3, and 4: 1-day weighed diet record combined with 1-day 24-hour recall and 5-day food intake tally	
			12-23 months (n = 2641)	Children 12-23 months from urban area		

Abbreviations: CF, complementary foods; NR, not reported (shaded).

Table 3. Reported Findings of Observed Intake Studies on Nutrient Adequacy From Complementary Foods in Breast-Fed Children Aged 6 to 23 Months, Nutrient Density, and Reported Intake as Percentage of Recommended Nutrient Intake by the Studies Included.

	Energy, kcal	Protein, g	Vitamin A, µg RAE	Thiamin, mg	Riboflavin, mg	Niacin, mg	Vitamin B6, mg	Vitamin B12, µg	Folate, µg	Vitamin C, mg	Calcium, mg	Iron, mg	Zinc, mg	Magnesium, mg
6-8 months														
Adrianopoli et al (2007)[23]														
Intake/d, mean	654.5	12.4	507.7	0.2	0.4	5.5	0.6	1	77.9	37.5	289.4	0.6	1.4	60.9
%RNI reported	106	136	127	81	108	134	128	198	97	125	72	7	35	113
Hotz and Gibson (2001)[34]														
Intake/d, median	175	4	7	NR	0.06	0.9	NR	NR	NR	NR	10	1.2	0.7	NR
ND/100 kcal	NR	2.3	2	NR	0.04	0.7	NR	NR	NR	NR	5	0.8	0.5	NR
%RNI reported	65	200	54	NR	30	28	NR	NR	NR	NR	3	11[a]	10[a]	NR
Paul et al (2011)[30]														
Intake/d, median	231.3	5	24.2	NR	NR	NR	NR	NR	25.5	NR	61.7	1.9	1.1	NR
Faber (2005)[40]														
Intake/d, median	NR	15	93	0.24	0.18	1.7	0.2	0.18	26	12	83	1.6	0.9	48
ND/100 kcal	NR	2.4	29	0.07	0.05	0.5	0.06	0.06	7	3.5	22	0.5	0.3	15
Gibson et al (2009)[36]														
Intake/d, median	142	3.3	0	0.04	0.04	0.75	NR	NR	NR	0	8.3	2.8	0.9	NR
ND/100 kcal	NR	2.3	0	0.03	0.02	0.43	NR	NR	NR	0	6.1	1.3	0.6	NR
%RNI reported	106	165	0	25	25	25	NR	NR	NR	0	3.9	31[a]	27[a]	NR
Lander et al (2010)[41]														
Intake/d, median	563.7	17.4	78	0.2	0.4	2.6	NR	NR	NR	2.1	190	1.6	2.5	NR
ND/100 kcal	NR	3	13.9	0.03	0.09	0.6	NR	NR	NR	0.3	44.4	0.3	0.5	NR
%RNI reported	227	870	124	100	200	87	NR	NR	NR	70	171	9	78[a]	NR
Kimmons et al (2005)[39]														
Intake/d, mean	121	2.7	12	0.05	0.06	0.92	0.09	0.1	10	1	35	0.49	0.34	13
%RNI reported	NR	103	44	67	80	50	50	160	89	100	87	8	40	70
Campos et al (2010)[32]														
Intake/d, mean	304	9.3	211	0.3	0.3	3.9	NR	NR	100	12.8	146	3.3	1.9	NR
ND/100 kcal	NR	3.1	68.2	0.1	0.08	1.2	NR	NR	33	4.7	47	1.1	0.6	NR

(continued)

Table 3. (continued)

	Energy, kcal	Protein, g	Vitamin A, μg RAE	Thiamin, mg	Riboflavin, mg	Niacin, mg	Vitamin B6, mg	Vitamin B12, μg	Folate, μg	Vitamin C, mg	Calcium, mg	Iron, mg	Zinc, mg	Magnesium, mg
Hernández et al (2011)[33]														
Intake/d, mean	324	9.4	537	0.4	0.4	4.3	NR	NR	85	24.7	205	4.7	2.3	NR
ND/100 kcal	NR	2.8	177	0.12	0.10	1.3	NR	NR	25	8	55	1.4	0.7	NR
Roche et al (2011)[38]														
Intake/d, mean	354	9.6	118.3	NR	NR	NR	NR	NR	NR	33.9	123.5	2.9	1.8	NR
ND/100 kcal	NR	2.3	27.6	NR	NR	NR	NR	NR	NR	8.4	27	0.7	0.3	NR
9-11 months														
Adrianopoli et al (2007)[23]														
Intake/d, mean	810	17.8	452.9	0.3	0.6	6.8	0.4	1.3	88	36.3	381.8	1	2	76.6
%RNI reported	118	186	113	112	141	171	136	253	110	121	95	11	48	142
Hotz and Gibson (2001)[34]														
Intake/d, median	358	10.3	123	NR	0.16	2.8	NR	NR	NR	NR	61	2.8	1.7	NR
ND/100 kcal		2.7	28	NR	0.04	0.8	NR	NR	NR	NR	18	0.8	0.5	NR
%RNI reported	80	332	302	NR	80	70	NR	NR	NR	NR	19	26[a]	24[a]	NR
Paul et al (2011)[30]														
Intake/d, median	411.9	9.4	49.2	NR	NR	NR	NR	NR	44.7	NR	96.9	3.2	1.8	NR
Faber (2005)[40]														
Intake/d, median	NR	17	92	0.26	0.16	1.9	0.23	0.09	45	10	78	1.7	1.2	60
ND/100 kcal	NR	2.5	28	0.06	0.04	0.5	0.06	0.01	10	3	19	0.7	0.3	15
Gibson et al (2009)[36]														
Intake/d, median	169	3.6	0	0.06	0.03	0.64	NR	NR	NR	0	7.6	2.1	0.9	NR
ND/100 kcal	NR	2.1	0	0.04	0.02	0.35	NR	NR	NR	0	4.1	1.2	0.6	NR
%RNI reported	74	116	0	35	17	21	NR	NR	NR	0	3.3	23[a]	26[a]	NR
Lander et al (2010)[41]														
Intake/d, median	616.7	16.8	61.4	0.2	0.4	3.8	NR	NR	NR	1.6	136	1.9	2.7	NR
ND/100 kcal	NR	3	9.2	0.03	0.06	0.6	NR	NR	NR	0.3	24.7	0.3	0.4	NR
%RNI reported	174	542	67	100	200	123	NR	NR	NR	30	60	10	84[a]	NR
9-11 months														
Kimmons et al (2005)[39]														
Intake/d, mean	147	3.6	20	0.06	0.08	1.22	0.08	0.09	16	4	43	0.65	0.44	18
%RNI reported	NR	110	48	73	85	59	50	164	100	113	94	9	45	81

(continued)

Table 3. (continued)

	Energy, kcal	Protein, g	Vitamin A, µg RAE	Thiamin, mg	Riboflavin, mg	Niacin, mg	Vitamin B6, mg	Vitamin B12, µg	Folate, µg	Vitamin C, mg	Calcium, mg	Iron, mg	Zinc, mg	Magnesium, mg
Campos et al (2010)[32]														
Intake/d, mean	491	15.6	399	0.5	0.4	5.7	NR	NR	156	17.2	226	5.3	3.1	NR
ND/100 kcal	NR	3.2	80.7	0.1	0.09	1.2	NR	NR	32	3.2	44	1.1	0.6	NR
Hernández et al (2011)[33]														
Intake/d, mean	524	18.6	812	0.9	0.6	5.8	NR	NR	131	25.6	239	4.9	3.2	NR
ND/100 kcal	NR	3.5	164	0.19	0.13	1.1	NR	NR	27	5.0	51	1.0	0.6	NR
Roche et al (2011)[38]														
Intake/d, mean	264	3.4	16.1	NR	NR	NR	NR	NR	NR	42.2	40.2	1.3	0.7	NR
ND/100 kcal	NR	1	4.1	NR	NR	NR	NR	NR	NR	17.1	15	0.4	0.2	NR
Hotz and Gibson (2004)[35]														
Intake/d, median	434.7	13.7	44	NR	0.18	2.6	NR	NR	NR	NR	71	3.3	1.9	NR
ND/100 kcal	NR	NR	21.4	NR	0.04	0.6	NR	NR	NR	NR	15	1	0.5	NR
%RNI reported	142	442	23	NR	100	84	NR	NR	NR	NR	72	31[a]	83[a]	NR
Perlas et al (2004)[37]														
Intake/d, median	294	5	7	0.06	0.07	1.1	NR	NR	NR	1.4	NR	NR	NR	NR
%RNI reported	59	134	12	32	29	25	NR	NR	NR	53	NR	NR	NR	NR
6-12 months														
Paul et al (2012)[31]														
Intake/d, mean	460	11.9	208	NR	NR	NR	NR	NR	74.2	NR	209	4.6	2.6	NR
ND/100 kcal	NR	2.5	54.4	NR	NR	NR	NR	NR	20.9	NR	49.8	0.8	0.4	NR
12-23 months														
Adrianopoli et al (2007)[23]														
Intake/d, mean	918	21.3	587.1	0.4	0.5	8.4	0.7	0.9	114.8	44.8	290	2	2.4	104.9
%RNI reported	103	196	147	82	96	140	140	182	72	149	73	34	60	175
Anderson et al (2008)[42]														
Intake/d, median	640	17.6	133	0.3	0.3	5.1	NR	NR	NR	26.6	132	4	1.5	NR
ND/100 kcal	NR	2.8	21.7	0.05	0.05	0.8	NR	NR	NR	4.4	18.7	0.6	0.2	NR

(continued)

Table 3. (continued)

	Energy, kcal	Protein, g	Vitamin A, μg RAE	Thiamin, mg	Riboflavin, mg	Niacin, mg	Vitamin B6, mg	Vitamin B12, μg	Folate, μg	Vitamin C, mg	Calcium, mg	Iron, mg	Zinc, mg	Magnesium, mg
Hotz and Gibson (2001)[34]														
Intake/d, median	412	11.6	164	NR	0.19	3.3	NR	NR	NR	NR	7.9	3.5	2	NR
ND/100 kcal	NR	2.7	38	NR	0.04	0.8	NR	NR	NR	NR	17	0.8	0.5	NR
%RNI reported	55	232	130	NR	48	46	NR	NR	NR	NR	40	60[a]	21[a]	NR
Gibson et al (2009)[36]														
Intake/d, median	292	7.3	0	0.1	0.09	1.37	NR	NR	NR	0	22.4	4.5	1.8	NR
ND/100 kcal	NR	2.3	0	0.03	0.02	0.42	NR	NR	NR	0	8	1.3	0.6	NR
%RNI reported	72	146	0	26	29	26	NR	NR	NR	0	6.5	78[a]	49[a]	NR
Lander et al (2010)[41]														
Intake/d, median	827.4	28.2	58.3	0.3	0.4	4.8	NR	NR	NR	2.7	142	3.2	4	NR
ND/100 kcal	NR	3.2	7.7	0.04	0.05	0.6	NR	NR	NR	0.4	16.4	0.4	0.5	NR
%RNI reported	156	553	47	75	133	92	NR	NR	NR	34	41	28	167[a]	NR
Roche et al (2011)[38]														
Intake/d, mean	1318	27.2	548.1	NR	NR	NR	NR	NR	NR	142.3	278.1	8.7	4.5	NR
ND/100 kcal	NR	2	39.3	NR	NR	NR	NR	NR	NR	11.2	21	0.6	0.3	NR
Hotz and Gibson (2004)[35]														
Intake/d, median	539.8	16	130	NR	0.24	4	NR	NR	NR	NR	111	4.8	2.6	NR
ND/100 kcal	NR	NR	21.8	NR	0.05	0.8	NR	NR	NR	NR	19.7	0.9	0.5	NR
%RNI reported	99	314	500	NR	77	77	NR	NR	NR	NR	32	72[a]	113[a]	NR
Perlas et al (2004)[37]														
Intake/d, median	368	8.2	28	0.09	0.10	1.78	NR	NR	NR	2	NR	NR	NR	NR
%RNI reported	44	130	16	21	23	24	NR	NR	NR	21	NR	NR	NR	NR
Baye et al (2013)[29]														
Intake/d, median	382	13.8	53.6	NR	NR	NR	NR	NR	NR	0.8	102	15	3.3	NR
ND/100 kcal	NR	3.4	12.8	NR	NR	NR	NR	NR	NR	0.2	25.9	3.8	0.7	NR
%RNI reported	69.7	276	42.5	NR	NR	NR	NR	NR	NR	10	29.5	277[a]	89[a]	NR

Abbreviations: ND, nutrient density; NR, not reported (shaded); RNI, recommended nutrient intake.
[a]Assuming moderate bioavailability (10%).

Table 4. Standardized Estimates of Dietary Adequacy From Local Foods as Percentage of the Estimated Needs and the Percentage at Risk of Inadequate Intakes, by Age-Group—Results of Observed Intake Studies.

	Energy	Protein	Vitamin A,	Thiamin	Riboflavin	Niacin	Vitamin B6	Vitamin B12	Folate	Vitamin C	Calcium	Iron	Zinc	Magnesium
6-8 months														
Adrianopoli et al (2007)[23,a]														
%RNI	106	136	127	67	100	138	200	143	97	125	72	6	34	113
%<EAR	NA	NA	NA	NA	NA	NA	NA	21	33	NA	NA	100	84	NA
Hotz and Gibson (2001)[34]														
%RNI-CF	87	200	11	NC	30	30	NC	NC	NC	NC	5	13	21	NC
Paul et al (2011)[30]														
%RNI-CF	115	250	38	NC	NC	NC	NC	NC	53	NC	29	21	33	NC
Faber (2005)[40]														
%RNI-CF	NC	750	148	120	90	57	NC	60	54	240	39	18	27	160
Gibson et al (2009)[36]														
%RNI-CF	70	165	0	20	20	25	NC	NC	NC	0	3.9	31	27	NC
Lander et al (2010)[41]														
%RNI-CF	279	870	124	100	200	87	NC	NC	NC	42	90	18	76	NC
Kimmons et al (2005)[39]														
%RNI-CF	60	135	19	25	30	31	NC	33	21	20	17	5	10	43
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	61	97	NA	NA	100	100	NA
Campos et al (2010)[32]														
%RNI-CF	150	465	335	150	150	130	NC	NC	208	256	69	36	58	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NC	NC	18	NA	NA	88	46	NA
Hernández et al (2011)[33]														
%RNI-CF	160	470	852	200	200	143	NC	NC	177	494	97	52	70	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	NC	22	NA	NA	71	39	NA
Roche et al (2011)[38]														
%RNI-CF	175	480	188	NC	NC	NC	NC	NC	NC	678	59	32	55	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	NC	NC	NA	NA	73	49	NA
9-11 months														
Adrianopoli et al (2007)[23,a]														
%RNI	118	185	113	100	150	170	133	186	110	121	95	11	49	142
%<EAR	NA	NA	NA	NA	NA	NA	NA	19	20	NA	NA	100	65	NA
Hotz and Gibson (2001)[34]														
%RNI-CF	117	332	134	NC	80	93	NC	NC	NC	NC	27	31	50	NC
Paul et al (2011)[30]														
%RNI-CF	60	98	12	NC	NC	NC	NC	NC	56	NC	24	34	44	NC

(continued)

Table 4. (continued)

	Energy	Protein	Vitamin A,	Thiamin	Riboflavin	Niacin	Vitamin B6	Vitamin B12	Folate	Vitamin C	Calcium	Iron	Zinc	Magnesium
Faber (2005)[40]														
%RNI-CF	NC	548	100	130	80	63	NC	30	94	200	34	19	35	188
Gibson et al (2009)[36]														
%RNI-CF	55	116	0	30	15	21	NC	NC	NC	0	3.3	23	26	NC
Lander et al (2010)[41]														
%RNI-CF	201	542	67	100	200	127	NC	NC	NC	32	60	21	79	NC
Kimmons et al (2005)[39]														
%RNI-CF	48	116	22	30	40	41	NC	30	33	80	19	7	13	56
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	68	84	NA	NA	100	100	NA
Campos et al (2010)[32]														
%RNI-CF	160	503	434	250	200	190	NC	NC	325	344	99	58	91	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	NC	7	NA	NA	65	25	NA
Hernández et al (2011)[33]														
%RNI-CF	171	600	883	450	300	193	NC	NC	273	512	105	54	94	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	NC	9	NA	NA	70	23	NA
Roche et al (2011)[38]														
%RNI-CF	86	110	18	NC	NC	NC	NC	NC	NC	884	18	14	21	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	NC	NC	NA	NA	100	91	NA
Hotz and Gibson (2004)[35]														
%RNI-CF	142	442	48	NC	90	87	NC	NC	NC	NC	31	36	56	NC
Perlas et al (2004)[37]														
%RNI-CF	96	161	8	30	35	37	NC	NC	NC	28	NC	NC	NC	NC
6-12 months														
Paul et al (2012)[31]														
%RNI-CF	181	458	267	NC	NC	NC	NC	NC	155	NC	95	51	78	NC
%<EAR-CF	NA	NA	NA	NA	NA	NA	NA	NC	0	NA	NA	100	0	NA
12-23 months														
Adrianopoli et al (2007)[23,a]														
%RNI	103	195	147	80	100	140	140	100	77	149	58	34	59	175
%<EAR	NA	NA	25	50	31	9	16	37	55	4	86	82	84	9
Anderson et al (2008)[42]														
%RNI-CF	117	352	106	75	100	102	NC	NC	NC	333	38	71	44	NC
Hotz and Gibson (2001)[34]														
%RNI-CF	75	232	130	NC	63	66	NC	NC	NC	NC	2	63	59	NC
Gibson et al (2009)[36]														
%RNI-CF	53	146	0	25	30	27	NC	NC	NC	0	6	80	53	NC

(continued)

Table 4. (continued)

	Energy	Protein	Vitamin A,	Thiamin	Riboflavin	Niacin	Vitamin B6	Vitamin B12	Folate	Vitamin C	Calcium	Iron	Zinc	Magnesium
Lander et al (2010)[41]														
%RNI-CF	151	564	46	75	133	96	NC	NC	NC	34	41	57	118	NC
Roche et al (2011)[38]														
%RNI-CF	241	544	435	NC	NC	NC	NC	NC	NC	1779	80	155	132	NC
%<EAR-CF	NA	NA	23	NC	NC	NC	NC	NC	NC	6	48	16	22	NC
Hotz and Gibson (2004)[35]														
%RNI-CF	99	320	103	NC	80	80	NC	NC	NC	NC	32	86	76	NC
Perlas et al (2004)[37]														
%RNI-CF	67	164	22	23	33	56	NC	NC	NC	25	NC	NC	NC	NC
Baye et al (2013)[29]														
%RNI-CF	70	276	43	NC	NC	NC	NC	NC	NC	10	29	268	97	NC

Abbreviations: NA, not available due to unavailability of EAR (shaded); NC, not calculated due to unavailability of data (shaded); EAR, estimated average requirement; EAR-CF estimated average requirements corrected for breast-milk intake); RNI, recommended nutrient intake; RNI-CF, recommended nutrient intake corrected for mean breast-milk intake.
[a]Adrianopoli et al[23] reported only total dietary intake, therefore, the RNI and EAR were not corrected for breast-milk intake.

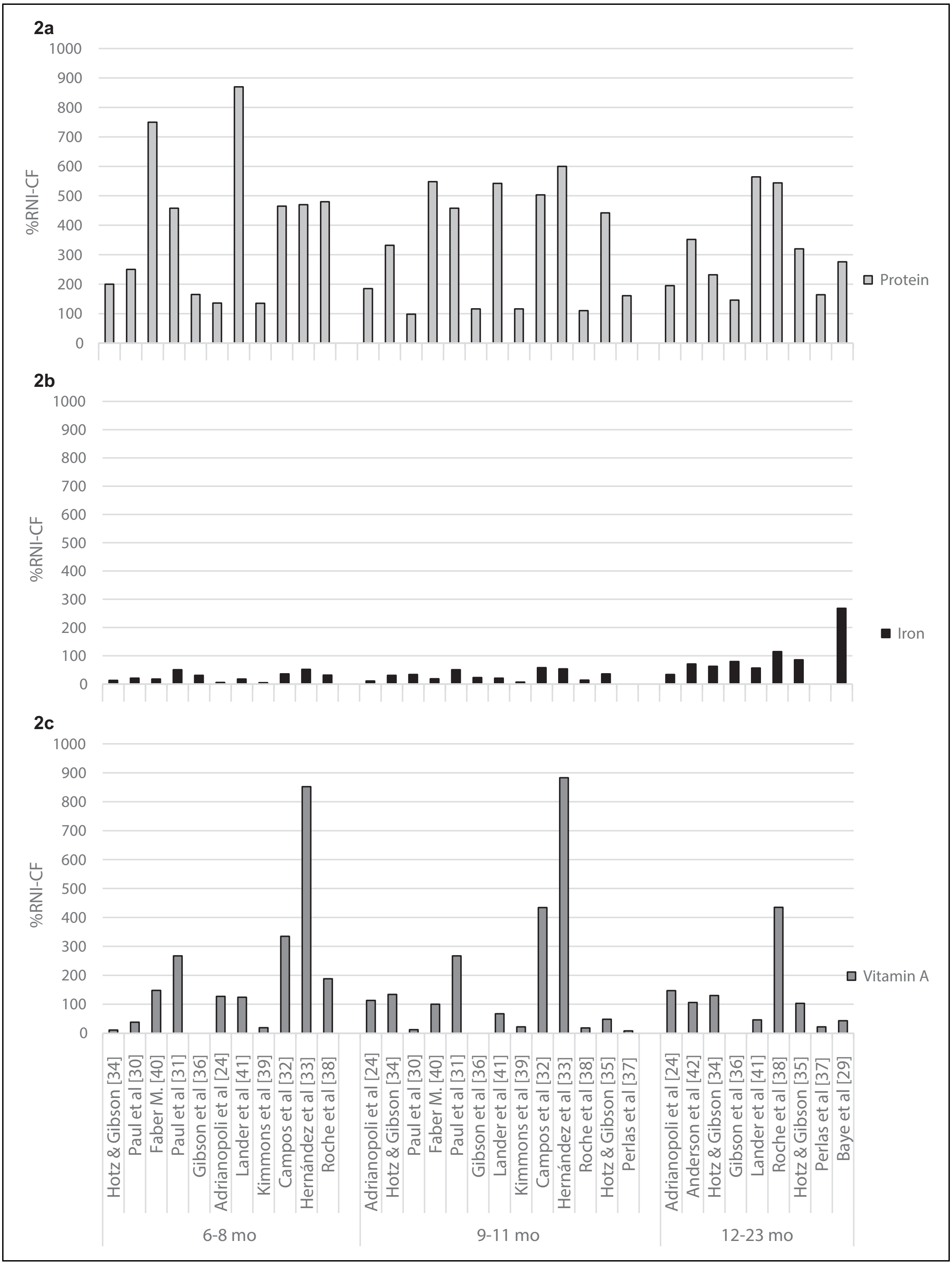

Figure 2. Mean or median protein (2a), iron (2b), and vitamin A (2c) intakes from locally available foods as reported in the observed intake studies, compared to the RNI from complementary foods (%RNI-CF) for children aged 6 to 8, 9 to 11, and 12 to 23 months. Y-axis represent mean intakes as percentage of the RNI-CF; x-axis represent the findings of the included observed intake studies for 3 age subgroups.

Results by Age Subgroups

The findings of the observed intake studies indicated calcium, iron, and zinc as the nutrients of concern for children aged 6 to 11 months. The highest %RNI-CF in children aged 6 to 8 months did not reach 100% for calcium (97%), iron (52%), and zinc (78%), indicating that for these nutrients none of the included studies reported intakes were reaching the estimated needs. The maximum %RNI-CF in children aged 9 to 11 months did not reach 100% for iron (58%) and zinc (94%). Only 1 of the 12 studies found a %RNI-CF slightly above 100% (ie, 105%) for calcium in children aged 9 to 11 months.[33] Six of 8 studies in children aged 12 to 23 months also reported %RNI-CF for iron and zinc below 100%. The fact that 2 studies[38,41] in this age subgroup reported no intake gaps for these 2 nutrients seems to suggest that meeting iron and zinc requirements from local foods can improve with age. The maximum %RNI-CF was equal or smaller than 80% for thiamine (reported by 5 of the 9 studies in this age-group), 77% for folate (reported by only 1 of the 9 studies), and equal or smaller than 80% for calcium (reported by 8 of the 9 studies) in children aged 12 to 23 months, suggesting that the requirements of these nutrients may be difficult to achieve in this age-group.

Children aged 6 to 11 months were meeting the estimated requirements for protein in all studies. Vitamin B6 intakes were adequate in the 1 study[23] reporting on this nutrient for this age-group. Children aged 12 to 23 months were meeting the estimated needs from local complementary foods for protein in all 9 studies that reported data for this age-group. Intakes of vitamin B6, vitamin B12, and magnesium were meeting the estimated requirements in the one study that reported on intakes for these nutrients.

For children aged 6 to 8 months and 9 to 11 months, dietary inadequacy, determined by the %<EAR-CF, could only be calculated for iron, zinc, vitamin B12, and folate, since no EARs have been established for the other nutrients for these age-groups. Dietary inadequacy was generally high for both iron and zinc among all 3 age-groups. For children aged 6 to 8 months, the %<EAR-CF for iron ranged from 71% to 100% and for zinc from 0% to 100%. Moreover, all 6 studies presenting findings for the 2 youngest age-groups (6-8 and 9-11 months) reported a %<EAR-CF higher than 50% for iron. Two of the 6 studies reported a %<EAR-CF higher than 50% for zinc in this age-group. For children aged 9 to 11 months, the %<EAR-CF for iron ranged from 65% to 100% and for zinc from 0% to 100%. Again, all 6 studies reported a %<EAR-CF higher than 50% for iron and 3 of the 6 for zinc in children aged 9 to 11 months. In addition to inadequate iron and zinc intakes, children aged 12 to 23 months were at risk of inadequate calcium intakes, ranging from 48 to 66 %<EAR-CF. Information on dietary adequacy for calcium was not available for the younger children (6-11 months) due to the lack of an established EAR for calcium for these age-groups.

Modeled Dietary Intakes From Locally Available Complementary Foods

The results reported by the 8 studies that investigated modeled dietary intakes from locally available complementary foods are presented in Table 5.

Overall, modeled dietary intakes from locally available complementary foods were adequate in all scenarios for protein and vitamin B12. Vitta and Dewey[24] did not identify any nutrient gaps in some best-case scenarios that were based on daily chicken liver consumption, for example, in children aged 9- to 11-months-old. The other 7 studies identified several nutrients gaps, even when dietary intakes were based on a best-case scenario. Among all age subgroups, modeled dietary intakes for iron and zinc were most frequently inadequate when compared to the RNI. Moreover, intake of B vitamins (ie, thiamin, riboflavin, niacin, and folate) and calcium was inadequate in most but not all studies and age-groups. Intakes of vitamin A and vitamin C was mostly adequate based on the best-case and optimized scenarios. However, when intakes of vitamin A and vitamin C were based on a worst-case scenario, they were inadequate (Table 5). Nutrient intake gaps remained for calcium, iron, and zinc (Table 5).

Table 5. Summary of the Reported Findings by the Included Modeled Intake Studies.[a]

	Energy	Protein	Vitamin A	Thiamin	Riboflavin	Niacin	Vitamin B6	Vitamin B12	Folate	Vitamin C	Calcium	Iron	Zinc
6-8 months													
Adrianopoli et al (2007)[23]													
%RNI	100	164	NA	<100	NR	NR	NR	NR	NR	NR	<100	<100	<100
Skau et al (2013)[19]													
%RNI Optimized	NR	168	121	74	74	86	94	183	55	133	100	22	73
%RNI best-case scenario	NR	170	140	77	75	88	102	193	60	148	107	24	73
%RNI worst-case scenario	NR	127	90	48	59	69	67	140	41	97	93	17	66
Vitta and Dewey (2012)[24,b]—Ethiopia													
%RNI best-case scenario	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	94	≥100
%RNI scenario 2	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	82	≥100
%RNI scenario 3	NR	NR	≥100	≥100	≥100	NR	90	≥100	≥100	≥100	≥100	26	68
Vitta and Dewey (2012)[24,c]—Bangladesh													
%RNI best-case scenario	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	88	≥100
%RNI scenario 2	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	78	≥100
%RNI scenario 3	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	37	82
Vitta and Dewey (2012)[24,d]—Vietnam													
%RNI best-case scenario	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 2	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 3	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	36	71
Fahmida et al (2014)[21]													
%RNI optimized	NR	NR	NR	≥100	≥100	<100	≥100	≥100	≥100	NR	<100	<100	<100
9-11 months													
Adrianopoli et al (2007)[23]													
%RNI	100	198	NR	NR	NR	NR	NR	NR	NR	NR	NR	<100	<100
Skau et al (2013)[19]													
%RNI optimized	NR	178	136	76	73	101	108	220	62	137	114	28	86
%RNI best-case scenario	NR	190	147	77	75	117	136	228	69	143	121	29	88
%RNI worst-case scenario	NR	130	85	52	58	78	77	158	40	97	100	21	72
Vitta and Dewey (2012)[24,b]—Ethiopia													
%RNI best-case scenario	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 2	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 3	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	35	83
Vitta and Dewey (2012)[24,c]—Bangladesh													

(continued)

Table 5. (continued)

	Energy	Protein	Vitamin A	Thiamin	Riboflavin	Niacin	Vitamin B6	Vitamin B12	Folate	Vitamin C	Calcium	Iron	Zinc
%RNI best-case scenario	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 2	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 3	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	52	≥100
Vitta and Dewey (2012)[24,d]—Vietnam													
%RNI best-case scenario	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 2	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	≥100	≥100
%RNI scenario 3	NR	NR	≥100	≥100	≥100	NR	≥100	≥100	≥100	≥100	≥100	49	86
Santika et al (2009)[20]													
%RNI optimized	NR	164	134	121	124	76	153	243	131	152	100	50	97
%RNI best-case scenario	NR	250	470	146	208	102	221	1171	217	217	149	63	110
%RNI worst-case scenario	NR	122	70	45	54	39	61	108	68	77	41	9	39
Fahmida et al (2014)[21]													
%RNI optimized	NR	NR	NR	≥100	≥100	≥100	≥100	≥100	≥100	NR	≥100	<100	≥100
12-23 months													
Adrianopoli et al (2007)[23]													
%RNI	NR	230	NR	NR	NR	NR	NR	NR	<100	NR	NR	<100	<100
Wu et al (2013)[22]													
%RDI	NR	103	532	67	223	NR	NR	NR	NR	NR	114	95	61
Fahmida et al (2014)[21]													
%RNI optimized	NR	NR	NR	≥100	≥100	≥100	≥100	≥100	≥100	NR	≥100	≥100	≥100
6-23 months													
Vossenaar and Solomons (2012)[27]													
Nutrient density/100 kcal	NR	NR	52.4	0.1	0.1	0.8	0.1	0.6	13.8	7.9	36.3	1.1	0.3
Fahmida et al (2014)[21]													
Low socioeconomic status	NR	NR	NR	<100	≥100	≥100	≥100	≥100	≥100	NR	≥100	<100	≥100
Middle socioeconomic status	NR	NR	NR	<100	≥100	≥100	≥100	≥100	<100	NR	≥100	≥100	≥100
Rural	NR	NR	NR	<100	≥100	<100	≥100	≥100	≥100	NR	<100	<100	<100
Periurban	NR	NR	NR	<100	<100	<100	<100	≥100	<100	NR	<100	<100	<100

Abbreviations: NR, not reported (shaded); RDI, reference dietary intake; RNI, recommended nutrient intake.

[a]Vitta and Dewey[24]: Best-case scenario: using only unfortified complementary foods regardless of costs or feasibility issues; scenario 2: unfortified complementary foods only with a minimum of 30% of energy from staple foods; scenario 3: unfortified complementary foods, with a minimum of 30% of energy from staple foods and food included from at least 5 food groups.

[b]Findings for Ethiopia.

[c]Findings for Bangladesh.

[d]Findings for Vietnam.

Discussion

It is generally recognized that, in practice, locally available foods do not meet requirements, especially for micronutrients, in most low-income countries and that this contributes to micronutrient deficiencies, growth faltering, and poorer child development during the first 2 years of life,[1] with potential adverse consequences for child health and development and later adult health.[43] The question whether these nutrient gaps can be filled by optimizing the intake of locally available foods has been a topic of debate. Our review provides an up-to-date analysis of the existing, published data, not only of the evidence on observed intakes but also of the potential of local foods to meet all nutrient requirements when diets are optimized through modeling with the use of locally available ingredients.

The findings of the observed intake studies included in this review indicate that diets consisting of locally available complementary foods alone are meeting requirements for protein for children 6 to 23 months of age. The nutrients most commonly inadequate and with the greatest gaps were calcium, iron, and zinc. Also for energy, vitamin A, thiamin, riboflavin, niacin, folate, and vitamin C, children did not always fulfill daily requirements with local foods. Only 2 of the observed intake studies reported on vitamin B6, vitamin B12, and magnesium, and therefore, no conclusions can be drawn on observed intakes for these nutrients based on this review. Optimizing food preparation techniques, for instance, by promotion of soaking techniques to reduce phytate content of a maize diet[35] or by promoting the processing of local foods so that infants could swallow them,[31] improved dietary intakes, but requirements for iron, zinc, and in some cases calcium were still not met. When modeling is used to optimize diets by increasing feeding frequencies or quantities of nutrient-dense foods, most of the nutrient requirements can be met, with the exception of iron and zinc. In some modeled intake studies, adequate intakes for calcium, thiamin, riboflavin, niacin, and folate were also difficult to reach. Our findings are consistent with those of previous reviews[3,5] in which calcium, iron, and zinc were identified as the most critical "problem nutrients" in the diets of children 6 to 23 months of age. In addition, the results of this review suggest that even when use of local ingredients is optimized, and despite the fact that intakes improve when diets are optimized, dietary adequacy for iron and zinc in particular cannot be met across age-groups and across different settings.

While interpreting these findings, several methodological constraints of our review have to be acknowledged. First, the %RNI-CF likely underestimates the actual contribution of complementary foods to the requirements of an individual, since RNIs are defined to cover the nutritional needs of 97.5% of the total population. In addition, our calculated %<EAR-CF was based on reported mean and SD of intakes, assuming that authors would only report SDs when intakes were normally distributed, which may not always have been the case.

In at least 3 of the 15 observed intake studies, diets made of locally available foods included the consumption of (commercial) fortified infant foods or Incaparina.[32,33,40] Faber[40] concluded that infants who consumed fortified infant products and fortified formula milk had significantly higher intakes of nutrients such as vitamin A, calcium, iron, and zinc, compared to infants who did not consume these products. However, even with consumption of fortified infant products, intakes were still inadequate for iron, due to inadequate nutrient densities of fortified infant foods, small quantities consumed and/or infrequent consumption of these products.

In addition to these methodological constraints, the total number of studies found was limited, and not all observed intake studies evaluated all nutrients for all the different age-groups. In particular, intakes of vitamin B6, B12, and magnesium were infrequently reported. For instance, only 2 studies reported on vitamin B6 intakes for 3 age-groups, and thus, no conclusions can be drawn on adequacy of observed intakes for these 3 nutrients.

The restriction to studies published in English language, the small sample size in some of the observed intake studies,[23,31,38,42] and the fact that some studies sampled deliberately children from rural[22,29,31,32,34-36,39,40] and/or poor communities[27,28,32,37,42] may raise questions on how representative the data from the observed intake studies are for usual dietary intakes of children in that specific country or region. In addition, the quality of some of the observed intake studies can be questioned since dietary assessment methods are generally recognized to be prone to biases. Several of the observed intake studies used single 24-hour recalls[23,34,37,39-42] and compared to recommended energy intakes from complementary foods as defined by Dewey and Brown,[17] some relatively high energy intakes from complementary foods were reported, for instance 1318 kcal for children aged 12 to 23 months[38] and 565 kcal for children aged 6 to 8 months.[41] The energy intake from complementary food in the latter study may reflect low mean breast-milk energy intake or may be related to overestimation from the single recall. The modeled intake studies typically included data from larger sample sizes and, in some cases, data from national representative dietary intake surveys and are therefore considered to be less prone to selection bias. However, there may have been publication bias toward reporting inadequate intakes for the modeled intake studies. In general, the question whether local complementary foods can in principle meet dietary requirements can best be answered by the modeled intake studies that model optimal diets using local foods. However, we only found 8 of these modeled intake studies.

Despite these methodological limitations, the findings on dietary inadequacy of the individual nutrients are remarkably consistent across the individual studies, representing different geographical and socioeconomic settings. This suggests that methodological constraints may have affected the individual estimates of the size of the dietary intake gaps but not the overall conclusion of this review that diets based on locally available complementary foods, even when optimized are not adequate to meet requirements of certain micronutrients and especially not for iron and zinc. The consistency of these findings with previous publications[3,5] provides further support for this conclusion.

The studies included in this review focused on evaluating intakes of energy, protein, and the most commonly reported and often deficient micronutrients. While most observed intake studies reported total daily energy intakes, only 2 of these studies[34,35] provided information on energy densities of the foods consumed. Low-energy density of local complementary foods is a major limitation for young children in low- and middle-income countries to meet daily energy requirements. Minimum energy densities for complementary foods have been recommended taking into account age-appropriate feeding frequencies and gastric capacities of young children.[17] The theoretical intake studies by definition modeled nutrient intakes assuming daily energy intakes equal to the average energy requirement for the age subgroup.[26]

None of the studies took protein quality into account, and there were no data available on fat or essential fatty acids intake, despite the growing body of evidence on the importance of essential fatty acids for infant and young child's growth and development.[44,45] In addition, surprisingly, none of the studies included in this review presented data on iodine intakes perhaps due to methodology issues with reliably estimating iodine intakes from foods and condiments. In Europe, several studies reported lower than recommended iodine intakes or low urinary iodine concentrations in infants receiving home-prepared complementary foods compared to those receiving iodine-fortified commercial infant foods,[46,47] whereas compared to other micronutrient deficiencies, iodine deficiency is common in Europe.[47]

In many of the populations evaluated in studies included in this review, children were either moderately malnourished or at risk of becoming so. Dietary reference values used may underestimate the actual requirements for optimal growth and development of malnourished children. The RNIs and EARs for micronutrients are based on requirements of healthy children.[6-8,12,14-16] The October 2008 consultation on moderate malnutrition reported that "the nutritional requirements of moderately malnourished children probably fall somewhere between the nutritional requirements for healthy children and those of children with severe acute malnutrition during the catch up growth phase."[48(pS465)] A study of malnourished children aged 3 to 6 years that showed positive impacts on linear growth used between 1.5 and 3 times the RNI for most micronutrients delivered in a fortified spread.[49] A study by Vossenaar and Solomons[27] was the only study included in this review where the authors modeled intakes separately against requirements for a hypothetical moderate malnourished girl (growing at the 15th percentile) and a normal weight boy (growing at the 50th percentile). Due to the larger body size and subsequent larger volumes of breast milk and food intakes, the diet of the normal weight boy had the most adequate intakes, whereas the diet of the underweight girl was inadequate for 8 of 10 nutrients examined. The authors concluded that the diet of the underweight girl was likely to be inadequate in more nutrients compared to the diet of the normal weight boy who could consume larger volumes of breast milk and food due to his larger body size.[27]

The findings of the 8 modeled intake studies included in this review suggest that the quality of diets can be substantially improved. Increasing the quantity or feeding frequency of nutrient-dense foods in the diet[19-24] and introducing new nutrient-rich foods[24] or food supplements[23,24] can partly overcome the nutrient gaps for many micronutrients, particularly in older children and in food secure environments.[42] Vitta and Dewey[24] concluded that diets made of local foods, available on the market, could theoretically meet all of the nutrient requirements, with the exception of iron. However, feasibility to prepare such diets was considered low, since they were about 3 to 8 times more expensive than diets that included micronutrient supplements, or because it would require the daily use of chicken liver, which is not traditionally given to young children in many settings.[24] In contrast, Adrianopoli et al,[23] Wu et al,[22] Skau et al,[19] Santika et al,[20] and Fahmida et al[21] modeled diets based on foods actually being provided and consumed by children and concluded that optimized diets made of these foods, within constraints for feeding frequency and food quantities, could not fulfill requirements for iron and zinc in all cases and, in some settings, for other micronutrients (calcium, folate, B vitamins) as well. Dietary adequacy for these nutrients was only reached when fortified foods or home fortificants such as micronutrient powders (MNPs) or small-quantity lipid-based nutrient supplements (sq-LNS) were added to the model.[19] Analyses using the cost-of-diet tool or a similar programming tool modeling costs in countries including Bangladesh, Kenya, Nigeria, Mozambique, Indonesia, and Nepal confirmed that theoretical optimized diets (ie, those that are able to fill all nutrient requirements) based on local available foods may be too expensive for most households.[50-54] One of these studies, evaluating the cost of nutritionally adequate diets for an average household size in Mozambique, suggests that multiple micronutrient fortification of maize flour could reduce the cost of the nutritious diet covering the combined nutritional needs of all members of an average household size by 18%.[51] When linear programming was used in Mozambique to formulate a nutritious porridge for children 12 to 24 months of age, with acceptable consistency using local ingredients only, the costs of this porridge were unacceptably high (US$1.85/day) for rural families within a tight budget. In this study, zinc in particular was identified as an economically limiting nutrient, suggesting that it would not be possible to reduce zinc deficiency by dietary changes in this setting without significantly increasing the costs of the foods consumed.[55]

The challenge of meeting the nutrient requirements for iron and zinc in the diets of young children has been discussed before[3] and is hypothesized to originate, at least in part, from the introduction of primarily cereal-based diets after the agricultural revolution, 10 000 years ago. Estimates of nutrient intakes before then, based on hypothetical diets of preagricultural humans, suggest that infants had much higher intakes of key nutrients than is true today and would have been able to meet their nutrient needs from the combination of breast milk and premasticated foods provided by their mothers.[3]

In summary, the findings of this review indicate that children aged 6 to 23 months are currently not meeting requirements for iron, zinc, and calcium with locally available foods, even in the 3 studies that reported the consumption of fortified infant products as part of the local diet. Optimizing the utilization of local foods by increasing frequency and quantity of nutrient-dense foods will improve intakes of these nutrients but is unlikely to fully cover requirements of iron and zinc. Also for energy, calcium, vitamin A, thiamin, riboflavin, niacin, folate, and vitamin C, children were not always able to fulfill daily requirements with locally available foods.

Our findings show that more effective behavioral change strategies to optimize the use of locally available foods can contribute to improved intakes and better meet the nutrient requirements of young children during this critical period of life. However, even when the use of local ingredients is optimized, in most settings, additional cost-effective strategies are required to ensure adequate intakes of iron and zinc, and in some contexts, this applies to calcium, folate, thiamin, riboflavin, and niacin as well. These cost-effective strategies may include enhancing the local availability of affordable and appropriately fortified infant food products or home fortificants such as MNPs or sq-LNS.

Authors' Note

S.J.M.O., M.J.v.L., L.M.N., and L.d.R. designed the research. S.J.M.O., B.B., L.B., and E.K. conducted the review and analyzed the data. S.J.M.O. and B.B. wrote the paper. S.J.M.O. had final responsibility of the content. All authors have read, provided input, and approved the final manuscript.

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