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Simulated effects of home fortification of complementary foods with micronutrient powders on risk of inadequate and excessive intakes in West Gojjam, Ethiopia

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Abstract

Home fortification of complementary foods (CFs) with multiple micronutrient powders (MNPs) is being scaled up in various countries, but little is known about the prevailing complementary feeding practices and the type and nutrient gaps to be filled with MNPs. The present study evaluated the complementary feeding practices of young children and simulated the risk of inadequate and excessive intakes associated with home fortification with MNPs. We have assessed the sociodemographic status, anthropometry, and complementary feeding practices of young children (N = 122) in Mecha district, rural Ethiopia. Using a 2-day, quantitative 24-hr recall, usual intakes of energy, protein, iron, zinc, and calcium were estimated. The risks of inadequate and excessive iron and zinc intakes with or without home fortification scenarios were assessed. The simulations considered intakes from CFs assuming average breast milk contributions and additional nutrients provided by the MNPs. Stunting was highly prevalent (50%) and was associated with a lower dietary diversity (P = .009) and nutrient intakes from the CFs. Median energy, zinc, and calcium intakes were below the estimated needs from CFs; protein needs were met. Median dietary iron intake appeared adequate, but 76%, 95% CI [68%, 84%], of children had inadequate intake (assuming low bioavailability), whereas another 8%, 95% CI: [3%, 13%], had excessive intakes. Simulation of daily and alternative day's fortification with MNP decreased the prevalence of inadequate iron and zinc intake but significantly increased the risk of excessive intakes that remained unacceptably high for iron (>2.5%). Untargeted MNP interventions may lead to excessive intakes, even in settings where poor complementary feeding practices are prevalent.

KEYWORDS

complementary foods, home fortification, iron calcium and zinc, micronutrient powders, nutrient intakes

1 | BACKGROUND

Globally, 161 million children under 5 years of age are undernourished (UNICEF/WHO/WB, 2015), and about two billion people are micronutrient deficient (WHO, 2007). Undernutrition and the associated micronutrient deficiencies disproportionately affect children in low- and middle-income countries (LMIC; UNICEF/WHO/WB, 2014). The period of complementary feeding is a particularly vulnerable time because energy and micronutrient requirements are very high relative to the amount of food consumed by the child (Dewey & Brown, 2003). The predominantly plant-based complementary diets with little animal source foods, fruits, and vegetables, as commonly consumed in LMIC, are associated with poor growth and micronutrient deficiencies (Mcevoy, Temple, & Woodside, 2012). Therefore, timely interventions that improve complementary feeding are needed to circumvent the short- and long-term adverse effects associated with undernutrition (De Onis et al., 2013).

In recent years, point-of-use fortification of complementary foods (CFs) with multiple micronutrient powders (MNPs) has received growing attention as a promising approach to tackle micronutrient deficiencies (Dewey, Yang, & Boy, 2009; WHO/FAO, 2006). The practice has been in use in several countries (Bhutta et al., 2008), and following promising results in reversing a number of micronutrient deficiencies (de Silva, Atukorala, Weerasinghe, & Ahluwalia, 2003; Stoltzfus et al., 2001), it is now being scaled up in various countries.

What has not followed pace is good characterization of prevailing complementary feeding practices, knowledge of the nutrient adequacy of CFs, and the type and nutrient gaps to be filled with MNPs. In light of the scarce data on nutrient intake, data on dietary diversity scores and prevalence of stunting and anemia have been used as proxies to inform the need for MNP interventions. Particularly, WHO recommends intervention with MNPs in settings with >20% of anemia prevalence (WHO, 2011).

However, anemia can have other causes than micronutrient deficiencies (e.g., infections). Dietary quality indicators such as dietary diversity scores do not always give information on the type and amount of nutrients to be supplemented with the MNPs. Thus, considering the possible adverse effects of supplying excessive amounts of nutrients through supplementation or fortification that includes increased susceptibility to infection or inflammation (Soofi et al., 2013; Zimmermann et al., 2010), efforts to monitor nutrient intakes with the aim of designing effective and safe micronutrient interventions are urgently needed.

In the present cross-sectional study, we have used a 2-day quantitative 24-hr recall collected on nonconsecutive days to characterize the prevailing complementary feeding practices and estimate the nutrient intakes of young children in a rural farming district, Mecha, Ethiopia. We have estimated the prevalence of inadequate intake of selected micronutrients (iron [Fe], zinc [Zn], and calcium [Ca]) and simulated the effect of MNP supplementation on the risk of inadequate and excessive nutrient intakes.

Key messages

- Inadequate complementary feeding was prevalent in the study area and was worst among stunted children.
- Although inadequate intakes of iron and zinc were prevalent, high prevalence of excessive intakes were also present.
- Prevalence of excessive intakes was exacerbated by untargeted home fortification with MNPs.
- MNP interventions should be guided by accurate data on nutrient intake possibly supported by biochemical data.

2 | MATERIALS AND SUBJECTS

2.1 | Study site and participants

This cross-sectional study was conducted from October 2013 to January 2014 in a food secure, Malaria endemic district, Mecha, West Gojjam, Amhara region, Ethiopia. In the region, the prevalence of stunting (42%) is very high and exceeds that of the national average (40%; CSA, 2014). The inhabitants are predominantly subsistence farmers producing maize (*Zea mays* L.), millet (*Pennisetum glaucum*), and pulses as food staples. In addition, teff (*Eragrostis tef*) is grown by many as a cash crop. Vegetables such as kale and potato are also grown. Traditional rearing of animals, mainly cattle and chicken are practiced, although rarely used for household consumption.

2.2 | Sample size determination

As part of a larger study that investigated child feeding, sample size calculations were made to enable comparison of two groups such as stunted or nonstunted and trained vs. untrained. The sample size was determined from power analyses calculated to detect a medium effect size (0.5 *SD* difference between with an α of 0.05 and power of 0.08). The estimated sample size was adjusted and rounded to 122 to allow for an approximately 15% nonresponse rate. Our data and sample size allowed us to characterize the mean energy intake with a 95% confidence interval of approximately ±30 kcal. The variance (between-subject; within-subject) were estimated for Fe (0.69; 0.32), Zn (0.34; 0.68), and Ca (0.34; 0.68).

2.3 | Sampling

Ten *kebeles* (smallest administrative unit) that are accessible enough for the collection of perishable samples were randomly selected. All households with children 12–23 months were identified by a census carried out before the survey. From each *kebele*, 12 children were randomly selected to participate in the study. The inclusion criteria were for the mother and child to reside permanently in the study area and for the child to be breastfed and apparently healthy. In the rare cases, when several children in the same household fulfilled the inclusion criteria, one child was randomly selected.

2.4 | Ethics

Ethical approval was obtained from the Human Ethics Committees of the College of Natural Sciences, Addis Ababa University, and the Amhara National Regional State Health Bureau. Verbal informed consent was obtained from the mother or guardian of each child after the purpose and methods of the study had been explained in detail to them in the presence of local health community workers and *kebele* (smallest administrative unit) administrators. All parents asked to participate in the study accepted. All questionnaires were translated into Amharic before the survey.

2.5 | Sociodemographic and anthropometric status

The sociodemographic characteristics of the participants were assessed using a pretested questionnaire that included questions on livelihood activities, education level of parents, ownership of livestock, and the size of land owned. All anthropometric measurements were made by the same person to avoid interexaminer errors. The length and weight of the children were measured in triplicate using standardized techniques, with the children wearing light clothing and no shoes. *Z*-scores for length-for-age (LAZ), weight-for-age (WAZ), and weight-for-length (WLZ) were calculated using the WHO multicenter growth reference data (WHO, 2006) using the software ENA 2007. Stunting, underweight, and wasting were defined as LAZ, WAZ, or WLZ, <−2, respectively. Complete anthropometric measurements were collected for 110 of the 122 studied children.

2.6 | Dietary intake assessment

An interactive quantitative 24-hr recall was conducted in-home with the caregiver of each child (*N* = 122), using the multiple-pass technique adapted and validated for use in developing countries (Gibson & Ferguson, 2008). A second day assessment was conducted on a subset of 40 children selected randomly from the study subjects, within 2 weeks and not exceeding a month. The second assessment was conducted on a different day of the week. This is in line with the suggestions of the IOM (2000) that at least 30–40 subjects per stratum is sufficient to adjust day-to-day variation in intakes within an individual. All days of the week were equally represented in the final sample. Experienced data collectors were locally recruited and trained in a classroom setting. This was followed by a pilot test on a group comparable to that of the actual study.

A day before intake was assessed (2 days before the recall), plates and cups were supplied to the caregivers, who were instructed not to change the dietary pattern of the child on the recall day. A demonstration was given on how weighing of food will be conducted. Portion size of foods consumed was estimated by direct weighing of salted replicas of actual foods prepared locally. Whenever found appropriate, graduated food models and common household measures were used.

For mixed dishes, the contribution (portion) of each ingredient to the total amount (g) consumed was estimated. In the rare cases where portion estimation of individual ingredients was difficult to obtain, average recipes were used.

2.7 | Compilation of local food composition database

For protein, Ca, Fe, and Zn contents of the most commonly consumed foods were based on results of biochemical analyses conducted in our laboratory; otherwise data were compiled from the Ethiopian food composition tables (Agren & Gibson, 1968; EHNRU, 1998; ENI, 1981) and published data (Abebe et al., 2007; Umeta, West, & Fufa, 2005) after adjusting the nutrient content for differences in moisture content.

The most commonly consumed foods identified and collected for analyses were: *Injera*, a fermented pancake-like bread, often prepared from finger millet and maize. *Injera* was served with a legume-based stew *shiro* made either from grass pea, broad beans, or field peas. Porridges made from a mix of wheat and maize were also common. Each of these foods were collected from randomly selected households (*n = 8*). Separate samples were collected for moisture content and other biochemical analyses.

Moisture content was determined by oven drying at 105 °C to constant weight. Protein content (*N* × 6.25) was determined by the Kjeldahl method based on determination of nitrogen content (AOAC, 2000).

Fe, Zn, and Ca were determined by using an atomic absorption spectrophotometer (SpectrAA 200; Varian, Mulgrave, Victoria, Australia) after dry ashing (AOAC, Association of Official Analytical Chemists, 1981). The accuracy and precision of mineral analyses were checked by analysis of certified reference materials (BCR 191: brown bread).

2.8 | Assessment of nutrient intake adequacy from CFs

The median daily intakes from CFs of 12- to 23-month-old children were compared with the estimated energy and nutrient intake requirements from CFs calculated from energy and nutrient requirements (Brown et al., 2004; Butte et al., 2000; FAO & WHO, 2004; FAO/WHO/UNU, 2004) assuming average breast milk intake and composition (Dewey & Brown, 2003; WHO, 1998). The adequacy of energy intakes were evaluated in two ways by

1. Comparing to the absolute energy requirements (kcal/day) as a percentage of estimated needs from CFs
2. Calculating the energy requirements of the children per kg/body weight to account for their small size. The estimated energy needs from CFs were then obtained by subtracting the energy contribution from breast milk.

We have assumed an average intake of 549 g/day (533 ml/day), which should provide ~346 kcal energy, 5.8 g protein, 154 mg Ca, 0.2 mg Fe, and 0.7 mg Zn (Dewey & Brown, 2003; WHO, 1998). Nutrient densities (per 100 kcal) were compared with desired values (Dewey & Brown, 2003). Median dietary diversity scores were calculated on the basis of seven food groups (WHO, 2008) and classified as low (0–2), medium (3–4), and high (>4; WHO, 2008).

2.9 | Prevalence of inadequate and excessive nutrient intakes

The prevalence of inadequate and excessive nutrient intakes, (i.e., from complementary food + average contribution from breast milk) before and after simulated fortification (+MNP), was estimated after adjusting for within-subject variation using the software Intake Monitoring Assessment and Planning Program. More details about the program and how to access it can be found in http://www.side.stat.iastate.edu/.The cutoff point method was used to estimate the prevalence of inadequate or excessive intakes of Zn and Ca. The approach involves calculating the proportion of children in the target group with usual intakes below the Estimated Average Requirements (EAR) for inadequate intakes, or above the Upper Limit (UL) for excessive intakes (FAO & WHO, 2004). For Zn, the EAR set by the International Zinc Nutrition Consultative Group (Brown et al., 2004), and the UL set by the Institute of Medicine (FNB/IOM, 2001) were used. For calcium, the EARs and ULs set by FAO were used (FAO & WHO, 2004). Because of the skewed distribution of estimated requirements, the prevalence of inadequate intakes of Fe was calculated using the full-probability approach, which is a statistical method that determines the probability of inadequacy of the usual nutrient intake level for each individual, and then averaging these individual probabilities across the group to estimate the prevalence of inadequate intakes for the group, assuming low, moderate, and high bioavailability. The nutrient intakes of stunted and nonstunted children were compared.

2.10 | Simulation of home fortification of CFs with MNPs

WHO recommends home fortification with MNPs in settings where the prevalence of anemia among 6 to 23 months infants and young children is >20%. Mecha, being a candidate for such interventions, we simulated the intake of additional nutrients from MNPs (daily/every 2 days). To this end, total Fe and Zn intakes (from CFs + average contributions from breast milk) and additional intakes from one sachet of MNP, taken every day or every other day, were simulated. The benefit and risk of additional intake of nutrients from MNPs were assessed, after adjusting for within-subject variations.

A 15-element MNP containing 10 mg of elemental Fe and 4.1 mg of Zn was used for this purpose. We then estimated the prevalence of inadequate and excessive intakes as described above.

2.11 | Statistical analyses

All continuous variables were checked for normality using Shapiro–Wilk test. Nutrient intakes (per day) and nutrient densities (per 100 kcal) were expressed as medians and interquartile range because of nonnormal distributions of some nutrients. Differences in the median energy and nutrient intakes between stunted and nonstunted children were examined using the nonparametric Mann–Whitney *U* test (two-tailed). In all comparisons, differences were considered statistically significant when $P < .05$. Statistical analyses were performed using SPSS statistical software package, version 20.

3 | RESULTS

3.1 | Sociodemographic and anthropometric status

More than 90% of the study participants were from subsistence farming household, but owned <1 ha of land. Nearly half of caregivers had ≥4 children. More than 70% of the households owned cows and chickens. Less than half of the mothers had at least a primary education (Table 1). The prevalence of stunting, underweight, and wasting were 50%, 34%, and 10%, respectively.

3.2 | Complementary feeding practices

The children were on average fed three times a day, with a significantly higher feeding frequency observed in nonstunted than in stunted children ($P < .001$). Less than 30% of the children consumed the minimum number (≥3) of food groups (Table 2). and as a result, the dietary diversity scores of most children (70%) were in the low (0–2) range. Significantly more children in the nonstunted group had a medium (3–4) dietary diversity score ($P = .005$).

The diets of the young children were predominantly cereal- and legume-based (Table 2). Although >70% of the households owned cows and chickens, consumption of animal source foods was very low (Table 2). Fruit and vegetable consumption including those that are vitamin A rich were also very low (~4%). Consumption of coffee was frequent (Table 2). and less than one third of the studied children were fed according to Infant and Young Child Feeding (IYCF) practices.

TABLE 1 Sociodemographic and anthropometric characteristics of mothers and young children (*N* = 122) aged 12 to 23 months from Mecha district, West Gojjam, Ethiopia, October 2013–January 2014

Sociodemographic characteristics	Mean ± *SD*/frequency (%)
Age of children (months)	16.2 ± 3.5
Proportion of male children	51.6
Age of mothers (years)	26 ± 6.1
Mothers educated ≥ primary school	30.3
Mothers' BMI	20.5 ± 2.2
Four or more children	45
Livelihood activity	
Farming	93.4
Small trading activity	4
Farming and small trading activity	2
Land size ≥1 ha	23.8
Own cows	85.2
Own chicken	73.8
Child nutritional status	
Stunted	50
Underweight	34
Wasted	10
LAZ	−2.01 + 0.9
WAZ	−1.63 + 0.9
WLZ	−0.33 + 1.4

Note. BMI = body mass index; LAZ = length-for-age *z* score; *SD* = standard deviation; WAZ = weight-for-age *z* score; WLZ = weight-for-length *z* score.

3.3 | Energy and nutrient intakes

Despite a low energy intake, median Fe and protein intakes met the estimated needs from CFs (Table 3). Cereals contributed to 77% of Fe and 54% of Zn intakes, whereas legumes contributed to 16% of Fe, 32% of Zn, and 20% of Ca intakes (Table S1). Dairy was the major source of Ca intakes (51%). Median iron intake met estimated needs from CFs, even when assuming low bioavailability. In contrast, Zn and Ca intakes were below the estimated needs. Stunted children had lower median energy ($P = .01$) and Zn ($P = .002$) intakes than nonstunted counterparts (Table 3).

3.4 | Nutrient density of the complementary diet

Protein and iron density of the complementary diets met the desired value (Table 4). but lower Fe density values were observed among stunted children ($P = .02$). In contrast, Zn (0.5) and Ca (20.7) were below the desired densities and were not related to stunting. Nevertheless, assuming medium instead of low bioavailability more than doubled the nutrient density of the complementary diet.

TABLE 2 Feeding practices by stunting categories: Young children (*N* = 122) aged 12 to 23 months from Mecha district, Ethiopia, October 2013–January 2014

	All (*N* = 122)		Stunted (*n* = 55)		Not stunted (*n* = 55)		*P* value
	n/mean	%/*SD*	n/mean	%/*SD*	n/mean	%/*SD*	
No. of meals per day[b]	3	0.71	2.8	0.68	3.4	0.53	< .001
Cereal products	120	98.3	53	96	55	100	.25
Legumes and nuts[a]	114	93	48	87	55	100	.006
Animal source foods							
Dairy	37	30	12	23	20	36	.07
Eggs	2	1.6	0	0	2	3.6	.15
Meat and poultry	0	0	0	0	0	0	
Vitamin A-rich fruits and vegetables	0	0	0	0	0	0	
Other fruits	5	4	3	5	2	3.6	.5
Tea	21	17	10	18	8	14.5	.4
Coffee	81	66	33	60	42	76	.05
Mean number of food groups (out of 7)[b]	2.2	0.49	2.1	0.45	2.3	0.44	.009
0–2[a]	87	70	46	84	33	60	.01
3–4[a]	35	29	9	16	22	40	.005
≥5	0	0	0	0	0	0	
Fed minimum number of solid/semi-solid foods[a,d]	108	89	43	80	54	98	.001
Fed minimum number of food groups or more[a,c]	35	29	7	13	24	44	.005
Minimum acceptable diet[b,e]	33	27	5	9	24	44	.001

Note. IYCF = infant and young child feeding.

[a]Statistically significant difference between stunted and nonstunted children according to Fisher's exact test (one-tailed).

[b]Difference between stunted and nonstunted was statistically significant according to Student's *t* test (two-tailed), equality of variances assumed.

[c]Minimum number of food groups: at least three times daily.

[d]Minimum number of solid/semi-solid foods: three times daily.

[e]Need to be fed solids/semi-solids at least three times daily and be fed a minimum of three food groups (WHO, 2008).

TABLE 3 Estimated daily intakes (median, M; Q1, Q3) of energy and selected nutrients from complementary foods relative to estimated needs among young children (122) aged 12 to 23 months, from Mecha district, Ethiopia, October 2013–January 2014

Nutrients	All (*n* = 122)	Stunted (*n* = 55)	Nonstunted (*n* = 55)	Estimated needs[a]
Energy (kcal)[b]	402 (284, 541)	348 (244, 479)	433 (330, 567)	548
(kcal/kg BW)				375
Protein (g)	26 (16, 50)	24 (13, 43)	29 (17, 47)	5
Ca (mg)	78 (37, 267)	66 (32, 227)	84 (41, 241)	346
Fe (mg)[b]	19 (12, 26)	16 (6.9, 23)	21 (16, 30)	11.4 (L), 5.6 (M)
Zn (mg)[b]	2.1 (1.3, 2.8)	1.6 (0.98, 2.6)	2.2 (1.6, 3)	7.6 (L), 3.8 (M)

Note. BW = body weight; M = median; Q1 = first quartile; Q3 = third quartile.

[a]Estimated needs from complementary foods are determined assuming average breast milk intake and composition as proposed by (WHO, 1998) and (Dewey & Brown, 2003); L = low bioavailability; M = medium bioavailability.

[b]Statistically significant difference between stunted and nonstunted children according to the Mann–Whitney *U* test: *P* = .01 for energy; *P* < .001 for iron; *P* = .002 for Zn.

3.5 | Prevalence of inadequate and excessive Fe, Zn, and Ca intakes

The prevalence of excessive and inadequate Fe, Zn, and Ca intakes estimated by assuming average breast milk intakes are presented in Table 5. Assuming low bioavailability, the prevalence of inadequate intakes were 76% for Fe and 100% for Zn, respectively.

Surprisingly, 8% of our population had excessive iron intakes. Although the prevalence of excessive intakes remains the same, because bioavailability has not been considered when setting the ULs, assuming medium and high bioavailability significantly reduces the prevalence of inadequate intake. Similar to Fe and Zn, inadequate Ca intakes were also highly prevalent, but excessive intakes were less than 1%.

3.6 | Simulation of the risk of inadequate and excessive intakes after home fortification

Fortification of the complementary diet with 10 mg of iron and 4.1 mg of zinc (standard formula) significantly decreased the prevalence of

TABLE 4 Median (Q1, Q3) nutrient densities of complementary foods consumed by young children (n = 122) aged 12–23 months in Mecha district, West Gojjam, Ethiopia, October 2013–January 2014

Nutrient density (/100 kcal)	All (n = 122)	Stunted (n = 55)	Non-stunted (n = 55)	Desired values
Protein (g)	8.1 (5.9, 10)	8.1 (5.9, 10.1)	7.8 (5.5, 9.1)	0.9
Ca (mg)[a]	20.7 (12, 4.3)	17.9 (11.5, 51.9)	23.1 (12.5, 57.8)	63
Fe (mg)[a]	4.7 (3.9, 5.6)	4.2 (3.2, 5)	4.9 (4.3, 5.7)	2.1 (L), 1.0 (M)
Zn (mg)	0.5 (0.4, 0.6)	0.5 (0.4, 0.6)	0.5 (0.4, 0.6)	1.4 (L), 0.6 (M)

Note. BF = breastfed; L = low bioavailability; M = medium bioavailability; Q1 = first quartile; Q3 = third quartile.

[a]Statistically significant difference between stunted and nonstunted children according to the Mann–Whitney U test: P = .02 for Fe-desired values were those calculated by Dewey and Brown (2003).

TABLE 5 The risk of inadequate and excessive intakes of selected nutrients from complementary foods supplemented with (simulated) or without MNPs, among young children in Mecha district, Amhara region, Ethiopia, October 2013 to January 2014

Nutrients (EAR)	Usual intake (without MNP)		Usual intake + MNP (10 mg Fe + 4.1 mg Zn)[a]			
			Daily		Every other day	
	Inadequate % [95% CI]	Excessive % [95% CI]	Inadequate % [95% CI]	Excessive % [95% CI]	Inadequate % [95% CI]	Excessive % [95% CI]
Iron[b]						
L—11.6	76 [68, 84]	8 [3, 13]	45 [36, 54]	20 [13, 27]	62 [53, 71]	13 [7, 19]
M—5.8	31 [23, 39]	8 [3, 13]	3.9 [0.46, 7]	20 [13,27]	13 [7, 19]	13 [7, 19]
H—3.9	13 [7.0, 19]	8 [3, 13]	<1	20 [13, 27]	2.4	13 [7, 19]
Zinc						
L—6.9	100	0	43 [34, 52]	52 [43, 61]	97 [94, 100]	2.8
M—3.4	70 [62,78]	0	0	52 [43, 61]	<1	2.8
H—2	6.3 [2, 11]	0	0	52 [43, 61]	0	2.8
Calcium	69 [61, 77]	<1		NA		

Note. The following UL were used: 40 mg/day for Fe, 7 mg/day for Zn, and 2,500 mg/day for calcium (FNB/IOM, 2001; WHO/FAO, 2006); L = low bioavailability; M = moderate bioavailability; H = high bioavailability; NA, Ca is not included in the formulation of standard MNPs. CI, 95% confidence interval.

[a]Assuming standard MNP composition containing doses of Fe and Zn recommended by(HF-TAG, 2013).

[b]EARs cannot be calculated from RNIs for these age groups because of the skewed distribution of requirements for iron for young children and menstruating women. Instead, the corresponding RNI values are given.

inadequate intake (Table 5). However, this has substantially increased the risk of excessive Fe and Zn intakes. Fortification on alternative days decreased the risk of excessive intakes, but the risk for Fe remained unacceptably high.

4 | DISCUSSION

The present study evaluated the feeding practice and nutrient intakes of young children in Mecha District, West Gojjam, Ethiopia. Half of the children surveyed were stunted. Inadequate feeding practices including low dietary diversity, suboptimal intakes of energy, Zn, and Ca were widespread and were particularly worse for stunted children. In contrast, Fe and protein median intakes met estimated needs despite a predominantly plant-based complementary diet. Simulation of a home fortification with MNP showed a decrease in the prevalence of inadequate intake of Fe and Zn, but was associated with a concomitant increase in the prevalence of excessive intakes.

The children in this area, such as in other parts of Ethiopia, relied predominantly on a monotonous plant-based diets with little consumption of animal-source foods, fruits, and vegetables (Baye, Guyot, Icard-Vernière, & Mouquet-Rivier, 2013; Gibson et al., 2009). Such low dietary diversity has been consistently found to be associated with stunting and micronutrient deficiencies in other LMIC (Kaibi, Steyn, Ochola, & Plessis, 2016; Rah et al., 2010). Similarly, nonstunted children in this study had significantly higher dietary diversity score, energy, and nutrient intakes (i.e., Zn and Fe). This further highlights the importance of interventions that improve feeding practices during this critical period of complementary feeding. We have previously reported that knowledge of caregivers about IYCF remain suboptimal and that delivery of nutrition education through the use of the health extension system can be instrumental, provided that the knowledge-sharing effectiveness and counseling skills of health workers are adequate (Abebe, Haki, & Baye, 2016; Gebremedhin et al., 2016).

Besides educational interventions, efforts to improve the Zn- and Ca-density of the CFs are needed. However, despite the reliance on plant-based diet, which are not a rich source of bioavailable iron (Hurrell & Egli, 2010), the median intakes or density of Fe met estimated or desired values even when assuming low bioavailability. Nevertheless, a significant proportion of the children were at risk of inadequate Fe intakes. Comparison of median intakes to estimated needs does not take into consideration the distribution of the usual intakes and thus is ill-equipped to estimate risks of inadequate or excessive intakes. Such discrepancies between estimates using EAR and Required Nutrient Intake often arise because of the wide variation in usual intakes (Olsen et al. 2006), which could have been exacerbated by soil Fe contamination that is often random, hence, affecting some foods (i.e., cereals such as teff) more than others (e.g., legumes) as reported by Baye, Mouquet-Rivier, Icard-Vernière, Picq, and Guyot (2014).

However, previous studies from Ethiopia consistently reported high Fe intakes and low prevalence of Fe deficiency despite reliance on plant-based diets (Baye et al., 2013; Gashu et al., 2016). A large proportion of this Fe is believed to be from extrinsic sources, possibly due to soil contamination during the processing of cereals (Baye et al., 2014). Little is known on the extent of which this Fe is bioavailable. Some earlier studies have suggested that 3–35% of Fe from soil could be bioavailable depending on the soil type (Hallberg & Björn-Rasmussen, 1981). Recent studies in Malawi and Ethiopia have also found low prevalence of Fe deficiency despite the reliance of plant-based diets (Gashu et al., 2016; Gibson et al., 2015). A recent report indicated that contamination with acidic soils may have a small, but nonnegligible contribution to human Fe nutrition (Gibson et al., 2015). Systematic evaluation of the bioavailability of such Fe from extrinsic sources warrants further in-depth investigation.

In settings such as Mecha, program implementers often guided by the high stunting prevalence, the poor infant feeding practices, and the low dietary diversity, and in the absence of data on dietary intake, often recommend intervention with MNP to improve the quality of CFs. However, with a closer look at our estimation of the prevalence of excessive intakes of 8%, which was above the 2.5% considered acceptable (WHO/FAO, 2006), regular MNPs containing Fe cannot be safely provided without some form of targeting. Indeed, our simulation of untargeted daily fortification with MNPs significantly reduced the prevalence of inadequate intakes, but has also resulted in unacceptably high excessive Fe intakes (20%). Fortification on alternative days reduced this figure to 13%, which was still unacceptably high. Considering that intake of excessive iron has been found associated with increased susceptibility to infections (Cross et al., 2015; Soofi et al., 2013b), reduced growth (Majumdar, Paul, Talib, & Ranga, 2003), and a more pathogenic gut microbiota (Jaeggi et al., 2015; Zimmermann et al., 2010), untargeted provision of MNPs in this setting may not be recommended.

Even more surprising was the high prevalence of excessive Zn intakes associated with the home fortification with a standard MNP containing 4.1 mg of Zn. Fortification on alternative days alone does not seem to resolve the problem, unless Zn forms of higher bioavailability are used. This has offset the benefit of decreasing the prevalence of inadequate Zn intake. Such excessive Zn intakes were previously reported for toddlers in the United States who have had high consumption of supplements or fortified foods (Butte et al., 2010; Sacco, Dodd, Kirkpatrick, & Tarasuk, 2013). However, studies on the possible adverse effects are rare, making it difficult to differentiate whether the problem is the use of inappropriate ULs or the presence of excessive intakes. The few studies that exist have indicated that there were no observed adverse effects on indicators of copper and Fe status with Zn intakes exceeding the UL (Bertinato et al., 2013; Wuehler, Sempértegui, & Brown, 2008). This, along with earlier reports of lack of effect of fortification in improving Zn status could suggest that the ULs might have been set too low, but more studies are clearly needed.

Several limitations need to be considered when interpreting our findings. First, the cross-sectional nature of the present study does not account for possible seasonal variations nor does it allow causal inferences to be made. However, the focus on "problem nutrients" little affected by seasonality like Fe, Zn, and Ca makes this limitation less serious. The present findings came from a single district and thus cannot be extrapolated to all districts of West Gojjam, Ethiopia. Nevertheless, our intake data was in close agreement with those of the National Food Consumption Survey (EPHI, 2013), suggesting that our findings may also apply to other similar settings in Ethiopia and elsewhere. Further limitation is that breast milk intake was not quantified, but this will have little implication to the intakes of Fe and Zn considering that breast milk is a relatively poor source of these nutrients after the age of 6 months (provides ≤2% of the requirements; Gibson, Ferguson, & Lehrfeld, 1998). The intakes of all nutrients contained in the MNPs were not simulated because of lack of a complete and accurate food composition data and resource constraints that did not permit analyses of all nutrients.

Notwithstanding the above limitations, the study revealed that the complementary feeding in the study area is suboptimal and is characterized by a low dietary diversity. Inadequate energy and nutrient intakes are widespread and were associated with stunting. Despite the reliance on such a predominantly plant-based diet, excessive Fe intakes were present, and were likely to be exacerbated by home fortification with MNPs. Although interventions with a standard MNP containing 4.1 mg of Zn led to a substantial decrease in the prevalence of inadequate Zn intakes, it has also led to unacceptably high proportions of children reaching the ULs. These findings remind the need for a more careful weighing of the potential risks and benefits of untargeted MNP interventions in Ethiopia and in similar settings around the world. Decisions to intervene should be guided by accurate data on nutrient intake possibly supported by biochemical data, and whenever possible by appropriate targeting.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

All authors were involved in developing the study design. ZA and KB looked for funding. ZA coordinated and supervised the fieldwork. ZA and KB analyzed and interpreted the data. ZA wrote the first draft of the manuscript. All the authors contributed to manuscript preparation.

REFERENCES

Abebe, Y., Bogale, A., Hambidge, K. M., Stoecker, B. J., Bailey, K., & Gibson, R. S. (2007). Phytate, zinc, iron and calcium content of selected raw and prepared foods consumed in rural Sidama, Southern Ethiopia, and implications for bioavailability. *Journal of Food Composition and Analysis*, *20*, 161–168.

Abebe, Z., Haki, G. D., & Baye, K. (2016). Health extension workers' knowledge and knowledge-sharing effectiveness of optimal infant and young child feeding are associated with mothers' knowledge and child stunting in rural Ethiopia. *Food and Nutrition Bulletin*, *37*(3), 353–363.

Agren, G., & Gibson, R. (1968). *Food composition table for use in Ethiopia*. Addis Ababa, Ethiopia: Child nutrition unit.

AOAC (Association of Official Analytical Chemists). (1981). *Official methods of analysis* (13th ed.). Gaithersberg, MD: AOAC.

AOAC (Association of Official Analytical Chemists). (2000). *Official methods of analysis* (17th ed.). Gaithersberg, MD: AOAC.

Baye, K., Guyot, J., Icard-Vernière, C., & Mouquet-Rivier, C. (2013). Nutrient intakes from complementary foods consumed by young children (aged 12–23 months) from North Wollo, northern Ethiopia: the need for agro-ecologically adapted interventions. *Public Health Nutrition*, *16*(10), 1741–1750.

Baye, K., Mouquet-Rivier, C., Icard-Vernière, C., Picq, C., & Guyot, J. (2014). Changes in mineral absorption inhibitors consequent to fermentation of Ethiopian injera: Implications for predicted iron bioavailability and bioaccessibility. *International Journal of Food Science and Technology*, *49*(1), 174–180.

Bertinato, J., Simpson, J. R., Sherrard, L., Taylor, J., Plouffe, L. J., Van Dyke, D., … Hayward, S. (2013). Zinc supplementation does not alter sensitive biomarkers of copper status in healthy boys. *The Journal of Nutrition*, *143*, 284–289.

Bhutta, Z. A., Ahmed, T., Black, R. E., Cousens, S., Dewey, K., Giugliani, E., … Shekar, M. (2008). What works? Interventions for maternal and child undernutrition and survival. *The Lancet*, *371*(9610), 417–440.

Brown, K., Rivera, J., Bhutta, Z., Gibson, R., King, J., & Lonnerdal, B. (2004). International zinc consultative group: Technical Brief Document #1. Assessment of the risk of zinc deficiency in populations and options for its control. *Food and Nutrition Bulletin*, *25*(supp l2), S99–203.

Butte, N. F., Wong, W. W., Hopkinson, J. M., Heinz, C. J., Mehta, N. R., & Smith, E. O. B. (2000). Energy requirements derived from total energy expenditure and energy deposition during the first 2 y of life 1–4. *American Journal of Clinical Nutrition*, *94*(7), 1558–1569.

Butte, N. F., Fox, M. K., Briefel, R. R., Siega-Riz, A. M., Dwyer, J. T., Deming, D. M., & Reidy, K. C. (2010). Nutrient intakes of US infants, toddlers, and preschoolers meet or exceed dietary reference intakes. *Journal of the American Dietetic Association*, *110*(12), S27–S37.

Cross, J. H., Bradbury, R. S., Fulford, A. J., Jallow, A. T., Wegmüller, R., Prentice, A. M., & Cerami, C. (2015). Oral iron acutely elevates bacterial growth in human serum. *Scientific Reports*, *5*, 16670.

CSA. (2014). *Ethiopia mini demographic and health survey*. Addis Ababa, Ethiopia: Central Statistical Agency.

De Onis, M., Dewey, K. G., Borghi, E., Onyango, A. W., Blössner, M., Daelmans, B., … Branca, F. (2013). The world health organization's global target for reducing childhood stunting by 2025: Rationale and proposed actions. *Maternal & Child Nutrition*, *9*(S2), 6–26.

de Silva, A., Atukorala, S., Weerasinghe, I., & Ahluwalia, N. (2003). Iron supplementation improves iron status and reduces morbidity in children with or without upper respiratory tract infections: A randomized controlled study in Colombo , Sri Lanka. *The American Journal of Clinical Nutrition*, *77*, 234–241.

Dewey, K., & Brown, K. (2003). Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs. *Food and Nutrition Bulletin*, *24*(1), 5.

Dewey, K., Yang, Z., & Boy, E. (2009). Review article systematic review and meta-analysis of home fortification of complementary foods. *Maternal & Child Nutrition*, *5*, 283–321.

EHNRU. (1998). *Food composition table for use in Ethiopia*. Addis Ababa, Ethiopia: Ethiopian Health and Nutrition Research Unit/Food Agriculture Organization.

ENI. (1981). *Expanded food composition for use in Ethiopia*. Addis Ababa, Ethiopia: Ethiopian Nutrition Institute.

EPHI. (2013). *Ethiopia national food consumption survey*. Addis Ababa, Ethiopia: Ethiopian Public Health Institute.

FAO, & WHO. (2004). *Vitamin and mineral requirements in human nutrition second edition. World Health Organization*. Rome, Italy: World Health Organization.

FAO/ WHO/ UNU. (2004). Human energy requirements. *FAO Food Nutr. Tech. Rep. Ser. No. 1*. Rome, Italy: Food and Agriculture Organization of the United Nations/World Health Organizations/United Nations University.

FNB/IOM. (2001). Dietary reference intakes. vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: Institute Of Medicine.

Gashu, D., Stoecker, B. J., Adish, A., Haki, G. D., Bougma, K., & Marquis, G. S. (2016). Ethiopian pre-school children consuming a predominantly unrefined plant-based diet have low prevalence of iron-deficiency anaemia. *Public Health Nutrition*, *19*(10), 1–8.

Gebremedhin, S., Baye, K., Bekele, T., Tharaney, M., Asrat, Y., Sc, M., … Reta, N. (2016). Predictors of dietary diversity in children 6–23 months of age in largely food insecure area of South Wollo, Ethiopia. *Nutrition*, *27*. http://doi.org/10.1016/j.nut.2016.06.002

Gibson, R. S., & Ferguson, E. L. (2008). An interactive 24-hour recall for assessing the adequacy of iron and zinc intakes in developing countries. Washington, DC and Cali: International Food Policy Research Institute (IFPRI) and International Center for Tropical Agriculture (CIAT).

Gibson, R. S., Ferguson, E. L., & Lehrfeld, J. (1998). Complementary foods for infant feeding in developing countries: Their nutrient adequacy and improvement. *European Journal of Clinical Nutrition*, *52*(10), 764–770.

Gibson, R., Abebe, Y., Hambidge, K., Arbide, I., Teshome, A., & Stoecker, B. (2009). Inadequate feeding practices and impaired growth among children from subsistence farming households in Sidama, Southern Ethiopia. *Maternal & Child Nutrition*, *5*(3), 260–275.

Gibson, R. S., Wawer Anna, A., Fairweather-Tait, S. J., Hurst, R., Young, S. D., Broadley, M. R., … Siyame, E. W. P. (2015). Dietary iron intakes based on food composition data may underestimate the contribution of potentially exchangeable contaminant iron from soil. *Journal of Food Composition and Analysis*, *40*, 19–23.

Hallberg, L., & Björn-Rasmussen, E. (1981). Measurement contaminated of iron absorption with iron from meals. *The American Journal of Clinical Nutrition*, *34*(12), 2808–2815.

HF-TAG. (2013). Manual on micronutrient powder (MNPs) composition: Guidelines and specifications for defining the micronutrient composition of single sercve sachets for specified target populations in low and middle income countries with high prevalence of anemia and mic. Geneva, Switzerland: Home Fortification Technical Advisory group.

Hurrell, R., & Egli, I. (2010). Iron bioavailability and dietary reference values. *The American Journal of Clinical Nutrition*, *91*(5), 1461S–1467S.

IOM (Institute of Medicine). Food and Nutrition Board (2000). *Dietary reference intakes: Applications in dietary assessment*. Washington, D.C.: National Academy Press.

Jaeggi, T., Kortman, G. A., Moretti, D., Chassard, C., Holding, P., Dostal, A., … Njenga, J. (2015). Iron fortification adversely affects the gut microbiome, increases pathogen abundance and induces intestinal inflammation in Kenyan infants. *Gut*, *64*(5), 731–742.

Kaibi, F., Steyn, N., Ochola, S., & Plessis, L. (2016). The relationship between agricultural biodiversity, dietary diversity, household food security, and stunting of children in rural Kenya. *Food Science & Nutrition*, (May), 1–12. doi:10.1002/fns3.387

Majumdar, I., Paul, P., Talib, V. H., & Ranga, S. (2003). The effect of iron therapy on the growth of iron-replete and iron-deplete children. *Journal of Tropical Pediatrics*, *49*(2), 84–88.

Mcevoy, C. T., Temple, N., & Woodside, J. V. (2012). Review article vegetarian diets , low-meat diets and health: A review. *Public Health Nutrition*, *15*(12), 2287–2294.

Rah, J. H., Akhter, N., Semba, R. D., Pee, S. D., Bloem, M. W., Campbell, A. A., … Kraemer, K. (2010). Low dietary diversity is a predictor of child stunting in rural Bangladesh. *European Journal of Clinical Nutrition*, *64*(12), 1393–1398.

Sacco, J. E., Dodd, K. W., Kirkpatrick, S. I., & Tarasuk, V. (2013). Voluntary food fortification in the United States: Potential for excessive intakes. *European Journal of Clinical Nutrition*, *67*, 592–597.

Soofi, S., Cousens, S., Iqbal, S. P., Akhund, T., Khan, J., Ahmed, I., … Foundation, M. G. (2013). Effect of provision of daily zinc and iron with several micronutrients on growth and morbidity among young children in Pakistan: A cluster-randomised trial. *Lancet*, *382*, 29–40.

Stoltzfus, R. J., Kvalsvig, J. D., Chwaya, H. M., Montresor, A., Albonico, M., Tielsch, J. M., … Pollitt, E. (2001). Effects of iron supplementation and anthelmintic treatment on motor and language development of preschool children in Zanzibar: Double blind, placebo controlled study. *BMJ (Clinical Research Ed.)*, *323*(7326), 1389–1393.

Umeta, M., West, C., & Fufa, H. (2005). Content of zinc, iron, calcium and their absorption inhibitors in foods commonly consumed in Ethiopia. *Journal of Food Composition and Analysis*, *18*, 803–817.

UNICEF/WHO/WB. (2014). Levels and trends in child malnutrition. In Levels and trends in child malnutrition (p. 4). New York: United nations emergency fund, division of data, research and policy.

UNICEF/WHO/WB. (2015). Update of UNICEF/WHO/World Bank database on child malnutrition, http://www.who.int/nutgrowthdb/estimates2014/en/ (accessed October 2016).

WHO. (1998). *Complementary feeding of young children in developing countries: A review of current scientific knowledge*. Geneva, Switzerland: World Health Organization.

WHO. (2007). *Preventing and controlling micronutrient deficiencies in populations affected by an emergency*. World Health Organization.

WHO. (2008). *Indicators for assessing infant and young child feeding practices*. Geneva, Switzerland: World Health Organization.

WHO. (2011). *Guideline: Use of multiple micronutrient powders for home fortification of foods consumed by infants and children 6–23 months of age*. Geneva, Switzerland: World Health Organization.

WHO Multicentre Growth Reference Study Group. (2006). WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatrics*, (Suppl 450), 76–85.

WHO/FAO. (2006). *Guidelines on food fortification with micronutrients*. World Health Organization.

Wuehler, S. E., Sempértegui, F., & Brown, K. H. (2008). Dose–response trial of prophylactic zinc supplements, with or without copper, in young Ecuadorian children at risk of zinc deficiency. *The American Journal of Clinical Nutrition*, *87*, 723–733.

Zimmermann, M. B., Chassard, C., Rohner, F., Goran, K. N. E., Nindjin, C., Dostal, A., … Hurrell, R. F. (2010). The effects of iron fortification on the gut microbiota in African children: A randomized controlled trial in Co ̂ te d'Ivoire. *The American Journal of Clinical Nutrition*, *92*, 1406–1415.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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