Eur J Nutr
DOI 10.1007/s00394-016-1351-5

ORIGINAL CONTRIBUTION

Concurrent iron and zinc deficiencies in lactating mothers and their children 6–23 months of age in two agro-ecological zones of rural Ethiopia

Kedir Teji Roba[1,2] · Thomas P. O'Connor[2] · Tefera Belachew[3] · Nora M. O'Brien[2]

Received: 13 April 2016 / Accepted: 27 November 2016

Abstract
Purpose The aim of this study is to examine the co-occurrences of low serum ferritin and zinc and anaemia among mothers and their children in two agro-ecological zones of rural Ethiopia.
Methods Data were collected from 162 lactating mothers and their breast fed children aged 6–23 months. The data were collected via a structured interview, anthropometric measurements, and blood tests for zinc, ferritin and anaemia. Correlation, Chi-square and multivariable analysis were used to determine the association between nutritional status of mothers and children, and agro-ecological zones.
Results Low serum levels of iron and zinc, anaemia and iron deficiency anaemia were found in 44.4, 72.2, 52.5 and 29.6% of children and 19.8, 67.3, 21.8, 10.5% of mothers, respectively. There was a strong correlation between the micronutrient status of the mothers and the children for ferritin, zinc and anaemia ($p < 0.005$). Deficiency in both zinc and ferritin and one of the two was observed in 19.1, and 53.7% of the mothers and 32.7 and 46.3%, of their children, respectively. In the 24 h before the survey, 82.1% of mothers and 91.9% of their infants consumed foods that can decrease zinc bioavailability while only 2.5% of mothers and 3.7% of their infants consumed flesh foods.
Conclusion This study shows that micronutrient deficiencies were prevalent among lactating mothers and their children, with variation in prevalence across the agro-ecological zones. This finding calls for a need to design effective preventive public health nutrition programs to address both the mothers' and their children's needs.

Keywords Zinc · Ferritin · Haemoglobin · Mother and children · Ethiopia

Introduction

In many developing countries, micronutrient deficiencies are major public health problems in young children and women especially during pregnancy and lactation [1]. Nutritional requirements during lactation are greater than during pregnancy [2]. The first two years of life are crucial for children's long-term physical, mental and emotional development [3]. Growing children require extra micronutrients to maintain optimal growth and development (including normal brain development and cognitive function) in addition to protein. Low status of iron, zinc and vitamin A often co-occur and has independent and interacting effects on health, growth and immunological response [4–7]. On the other hand, a competitive interaction was reported between zinc and iron absorption in humans—zinc inhibits iron absorption and iron also inhibits zinc absorption when both were administered simultaneously [8]. Iron deficiency is the most common cause of nutritional anaemia and is the most common micronutrient deficiency worldwide; it has negative effects on the motor and mental development of young children [9, 10]. Similarly, low zinc status has a negative influence on growth and development and increases the risk of diarrhoea and

✉ Nora M. O'Brien
nob@ucc.ie
http://publish.ucc.ie/researchprofiles/D018/nob

1 College of Health and Medical Science, Haramaya Univesity, Dire Dawa, Ethiopia

2 School of Food and Nutritional Science, University College Cork, Cork, Ireland

3 Department of Population and Family Health, College of Public Health and Medical Sciences, Jimma University, Jimma, Ethiopia

Published online: 09 December 2016

acute respiratory infections among children [11–13]. In this study we focused only on iron and zinc micronutrient deficiencies due to financial constraints. However, it is important to note that other micronutrient, in particular vitamin A, and macronutrient intakes may be problematic in developing world countries such as Ethiopia. In addition to poor dietary intake of iron, anaemia can be caused by deficiencies of vitamin A or vitamin B12, chronic infections and parasite infestations.

It is estimated that 22% of the maternal deaths around the globe are related to severe anaemia [14, 15]. In Ethiopia, the magnitude of anaemia, zinc and iron deficiency among mothers and children is reported to be very high. A cross-sectional study conducted in Gondar among non-pregnant women reported prevalence of 74% for zinc and 55% for iron deficiencies, respectively [16]. A cross-sectional study among 700 pregnant mothers in rural Sidama, South Ethiopia, showed that 53% of them were deficient in zinc [17]. Another study conducted in 2008 among 22,861 reproductive age group among nine administrative region of Ethiopia by Umeta et al. [18] reported that 30.4% were anaemic, 49.7% were iron deficient (ID) and 17% had iron deficiency anaemia (IDA). A single study documenting the magnitude of ferritin status among lactating mothers in a slum of Addis Ababa showed that the prevalence of low ferritin status was 22.3% [19]. Studies of anaemia prevalence in children reported levels of 66.6% in children 6–23 months old in Wag-Himra Zone, Northeast Ethiopia [20], and the Ethiopian Demographic and Health Survey (EDHS) indicated 60.6% of children 6–23 months were anaemic [21], while 37% of under five children were anaemic in Kilte Awulaelo Woreda, Northern Ethiopia [22].

No study has been published to our knowledge on the interrelation of micronutrient deficiencies among lactating mothers and their children in Africa, particularly in Ethiopia. Most studies have focused on only one micronutrient or on one segment of a population group, whereas many populations can be expected to be deficient in several micronutrients at the same time. The aim of this study was to explore the prevalence of concomitant micronutrient deficiencies in lactating mothers and their children (6–23 months) across agro-ecological zones of rural Ethiopia.

Materials and methods

Study area and participants

This study was conducted in the Babile, Enderta and Hintalowajirat districts of Ethiopia from January to February 2014. Babile District (Woreda), which is 560 km away from Addis Ababa, in the eastern part of Ethiopia, is a lowland agro-ecological area. Its altitude ranges from 950 to 2000 m above sea level, and data were collected from 1000 to 1500 m above sea level. The major agricultural product for consumption is sorghum, and oil seeds and groundnuts are used as cash crops. Hintalo Wajirat and Endreta districts (683 and 773 km away from Addis Ababa in the Northern part of Ethiopia, respectively) represented midland agro-ecological areas. Data were collected from an altitude of greater than 2000 m above sea level. The major produce in these areas are cereals (teff and barley), and some people are involved in animal husbandry. A community-based study was conducted in four kebeles randomly selected from each geographical area (lowland and midland).

In this study, a total of 216 lactating mothers with a child 6–23 months of age were interviewed across both agro-ecological zones. Out of the 216 mothers who were interviewed, 202 of them and their children (6–23 months of age) provided blood samples. Of these 202 mother–child pairs, blood samples from 162 mother–child pairs were tested for micronutrients. Forty mother–child samples were not tested due to insufficient blood sample being obtained particularly in the case of the smaller children, or sample haemolysis. Thus, data from 162 mother–child pairs were included in this study: 82 mother–child pairs in households in the lowland area and 80 mother–child pairs in households in the midland area. After interview in their respective houses, mothers were given appointments to bring their children to the local clinic for a physical check-up by a medical practitioner the next morning. The first author (Dr. KTR) was present in the clinic to ensure the identity of the mothers who participated in the study. After through explanations and consent, blood samples were collected in the morning from both mothers and children.

Blood collection, serum separation and micronutrient measurement

Three to five millilitres of venous blood sample from the antecubital vein were taken from each study subject. The samples were taken in the morning (from 8:00 to 10:00 a.m.) [23] and were aliquoted into tubes without anticoagulants by a trained health professional. Samples were clotted and centrifuged to separate serum. The serum was stored frozen at −20 °C and transported by plane to the Ethiopian Public Health Institution (EPHI; http://www.ephi.gov.et), Addis Ababa. Serum ferritin, an indicator of iron stores, was analysed using an enzyme-linked immunosorbent assay (ELISA) with a fully automated Elecsys 1020 using commercial kits purchased from Boehringer Mannheim, Germany by a senior medical technologist. Serum ferritin (SF) levels were classified as low if <15 µg/l as recommended by WHO [24, 25].

A small portion of whole blood from the syringe was used to test haemoglobin level of the mothers and children immediately on site by using portable HemoCue analyser (HemoCue® Hb 301). The cut-off point for anaemia was based on WHO (2011) recommendation for non-pregnant mothers. This procedure was validated elsewhere in resource poor settings [26]. Level of anaemia was classified as: mild anaemia (Hgb 10–11.9 g/dl), moderate anaemia (Hgb 7–9.9 g/dl) and severe anaemia (Hgb less than 7 g/dl). Haemoglobin reading levels were adjusted for altitude by 0, −2, −5, −8 and −13 for altitudes of <1000, 1500, 2000 and 2500 m above sea level, respectively. We did not collect data above 2500 m [27]. Iron deficiency anaemia was defined as serum ferritin less than 15 µg/l and haemoglobin less than 12 g/dl [27].

To determine zinc, sera derived from the non-fasting blood samples collected in the morning (8.00–10.00 a.m.) were shipped to EPHI in dry ice and polystyrene packaging material. Samples of serum were collected into zinc-/metal-free vacutainers, and gloves were free of talcum powder. The concentration of zinc in serum was determined at the National Food, Medicines, Health Service Administration and Control Authority (FMHACA) laboratory by using Shimadzu Flame Atomic Absorption Spectroscopy (AA 6800 model, Japan). Serum sample (200 µl) was added into a trace metal-free plastic test tube and diluted with 6% butanol in 1:5 ratios. Calibration of the Atomic Absorption Spectrophotometer (Shimadzu) was carried out using series of zinc standards 0, 0.1, 0.2, 0.3 and 0.4 ppm by dilution from stock of 1000 ppm AAS zinc standard. Each series of standards was diluted with 5% glycerol to be equivalent with the viscosity of serum. Zinc concentration was measured using an air-acetylene flame at a wavelength of 213.9 nm and a slit width of 0.7 nm. The results were calculated from two runs [28]. To minimize the risk of contamination, all glassware and plastic tubes used were immersed in 10% (v/v) solution of nitric acid for 24 h, washed with distilled water and rinsed with deionized water before use and gloves free from talcum powder were used. We used a cut-off value for serum zinc of 65 µg/dl, for children and 66 µg/dl for mothers as recommended by the International Zinc Nutrition Consultative Group (IZincCG) [23].

Socio-demographic status and anthropometric measures

The following information was obtained from mothers during a face-to-face interview and recorded onto a questionnaire: health status of the child, such as age, gender, illness in the 2 weeks prior to the interview; profile of the mother, such as age of the mother, literacy (mother being able to read and write), marital status, occupation, parity, birth interval, family size and health services utilization; environmental services, such as owning a latrine and source of drinking water (pipe water vs. water from unprotected spring, river or well). The questionnaire was developed in English, translated into the local language (Tigrigna and Afan Oromo) and pretested in non-study households in a similar community before application. Finally, mothers were given appointments to bring their children to the local clinic for a physical check-up by a medical practitioner. The inclusion criteria for mothers were: biological mother of a child of 6–23 months of age living in the resident area at least for greater than one year, apparently healthy (no sign and symptoms of illness in the past 15 days such as acute fever or who reported any infection like malaria, diarrhoeal disease, tuberculosis) and reported as non-pregnant by having regular menstrual cycle. In this study, due to unavailability of reagents to assess CRP and AGP we did not test for these markers of inflammation, and alternatively we excluded children and mothers with a current history of acute fever or who reported any infections such as malaria, diarrhoeal disease, tuberculosis, and HIV/AIDS or who had visible signs of oedema. Information on the utilization of salt was collected, and salt used during the previous night was tested on site for the presence of iodine or not.

The anthropometric measurements for children and their mothers were performed using the standardized procedures recommended by WHO [29, 30]. The weights of the lactating women were measured to the nearest 0.1 kg on a battery-powered digital scale (Seca 770, Hanover, Germany), with a weighing capacity of 0–140 kg. Based on standard anthropometric techniques [31], the heights were measured to the nearest 0.1 cm, using a wooden height-measuring board with a sliding head bar. Mid-upper arm circumferences (MUAC) were measured using a non-stretchable MUAC tape (MUAC measuring tape/PAC-50) [31] on the left upper arm of the mothers. The study subjects were barefoot and in light clothes when we measured their weight and height. Children were weighed together with the mother of the child, and the child's weight was calculated by subtracting the respective mother's weight. This was recorded on the form during the fieldwork and the calculations confirmed later on by supervisors. Children's height/length was measured to the nearest one centimetre with locally made portable devices equipped with gauges (SECA 2006 sliding board). To avoid variability among the data collectors, all the anthropometric measurements were taken by two different data collectors and the two measurements were compared. Where there was a still difference after repeat measurement by the data collectors, the first author (KTR) re-measured for validation—this was necessary for only one child. The BMI [weight/height^2 (kg/m^2)] was calculated, and the threshold of 18.5 kg/m^2 was used to identify the underweight women.

Dietary intake assessment

Dietary intake was assessed by simple questionnaire that allowed all types of foods consumed during each of the 24 previous hours to be noted and dietary diversity score (DDS) calculated. In the calculation of dietary diversity score we used seven food group classifications for children over a given 24-h reference period—grains/roots/tubers; legumes and nuts; dairy products, vitamin A-rich fruits/vegetables; other vegetables; meat/poultry/fish; eggs [32]. Maternal dietary diversity was calculated using nine food groups: all starch foods; dark green vegetables (DGLV); other vitamin A-rich fruit and vegetables; other fruits and vegetables; organ meat; meat and fish; eggs; legumes and nuts; dairy products [33]. All mothers were lactating and all children were breastfed. Detailed data regarding infant and young child feeding (IYCF) practices in this study group have previously been published [34]. None of the households in this study consumed fortified foods or food supplements. In addition to DDS, seven day food frequency questionnaires were used to determine frequency of consuming each food group and consumption of foods rich in zinc and iron inhibitors (phytates). Methods for this data collection were published elsewhere [35]. The dietary and food frequency assessments were made for both mothers and children. Minimum dietary diversity for children was defined as consuming four or more than four food groups from seven group classifications [32]; minimum dietary diversity for women was defined as consuming five or more food groups from nine food group classifications [33]. Consumption of tea/coffee was categorized as mothers or children who consumed tea or coffee four or more times in the previous week and those who consumed tea/coffee less than four times. The zinc bioavailability inhibitor food group score was derived from mothers who consumed bread, millet, pulses, soybean and tea in the last 24 h. The flesh food group was computed from consumption of red meat, organ meat, poultry and fish. Vitamin A-rich food group (pre-vitamin A carotenoids) was calculated from consumption in the previous 24 h of yellow or orange fruits, other vegetables, carrots and other roots. These data were derived from seven day food frequency questionnaires.

Variables

The dependent variables were nutritional and micronutrients (zinc and iron) status of mothers and children. The independent variables were the mothers' socio-demographic, economic, health and sanitation statuses; and health service utilization and feeding style. The nutritional knowledge of the mothers, their dietary diversity score and meal frequency and the health seeking behaviour of the family were also considered.

Data processing and analysis

The data were double entered, by separate data clerks, into EPI Data version 3.1. Data cleaning and editing were undertaken before the analysis. Descriptive, Pearson's correlation coefficients and Chi-square tests were performed to determine the association between the infants' and their respective mothers' micronutrient, nutritional and dietary diversity data. p values of 0.05 and below were used as cutting points to determine the statistical significance of the associations between the variables. The statistical analysis was carried out using SPSS (version 16), Stata (version 11) and WHO Anthro for children's anthropometric Z score calculation. The magnitude of malnutrition in the infants was assessed by weight-for-length Z score (WLZ), weight-for-age Z score (WAZ) and length-for-age Z score (LAZ). Based on WHO 2006 reference cut-off points, below negative two Z score is categorized as malnourished.

Ethical consideration

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects/patients were registered and approved by University College Cork, Ireland and Haramaya University College of Health and Medical Sciences Institution, Ethiopia, Research Ethics Review Committees. Subsequently, the final registration and approval of the protocol was granted by the Ethiopian National Ministry of Science and Technology Ethical Review Committee with registration no of 310/592/06 dated 08/05/06 Ethiopian calendar. Informed consent was obtained from the mothers, and verbal informed consent was obtained from the caregivers of the children; they were informed that they have the right to refuse or exit from the study at any time and refusing to participate in the study would not have any negative implications for them. Verbal consent was witnessed and formally recorded. Children and women who were found to be under nourished during assessment were referred to the nearest health institution for health care services.

Results

As described earlier, blood samples from 162 mother–child pairs were analysed for micronutrients. Of the 162 mothers, 69.8% were illiterate, only 24.7% had their own source of income, 58% had parity greater than or equal to four, only 30.9% completed four focused antenatal care sessions (ANC), and 42.9% had birth interval of less than two years (Table 1). The number of the lowland mothers whose parity was less than or equal to three (54.8%) was

Table 1 Distribution of selected socio-demographic and maternal characteristics of lactating mothers by agro-ecological zone of rural Ethiopia

Variables	Category	Total *N* (%)	Lowland *N* (%)	Midland *N* (%)	X^2	*p* value
Mother's education	Illiterate	113 (69.8)	63 (76.8)	50 (62.5)	3.94	0.47
	Attended school	49 (30.2)	19 (23.2)	30 (37.5)		
Parity	3 and below	60 (42.0)	40 (54.8)	20 (28.6)	10.1	0.001
	≥4	83 (58.0)	33 (45.2)	50 (71.4)		
ANC follow	<4	112 (69.1)	69 (86.3)	43 (53.8)	17.5	<0.001
	=4	50 (30.9)	13 (13.7)	37 (46.2)		
Family size	1–5	73 (45.1)	41 (50.0)	32 (40.0)	1.64	0.21
	>5	89 (54.9)	41 (50.0)	48 (60.0)		
Number of children <5 years	1 Child	67 (41.4)	25 (30.5)	42 (52.5)	1.00	0.03
	2 Children	85 (52.5)	47 (57.3)	38 (47.5)	4.9	–
	3 Children	10 (6.1)	10 (12.2)	0 (0.0)	–	
Household own toilet	Yes	71 (43.8)	40 (48.8)	31 (38.8)	1.67	0.2
	No	91 (56.2)	42 (51.2)	49 (61.2)		
Ever used contraceptives	Yes	88 (54.3)	32 (39.0)	56 (70.0)	15.7	<0.001
	No	74 (45.7)	50 (61.0)	24 (30.0)		
Birth interval	First birth	12 (8.1)	9 (11.0)	3 (4.6)	1.00	
	1–2 years	63 (42.9)	44 (53.7)	19 (19.2)	0.02	0.9
	≥2	72 (49.0)	29 (35.4)	43 (66.2)	1.62	0.2
Have index child vaccination card	Yes	85 (52.8)	15 (18.3)	71 (88.8)	80.7	<0.001
	No	76 (47.2)	67 (81.7)	9 (11.2)		
Mother's occupation	Farmer	150 (92.6)	77 (93.9)	73 (91.2)	0.4	0.5
	Petty trader	12 (7.8)	5 (6.1)	7 (6.2)		
Mother has own source of income	Yes	40 (24.7)	31 (37.8)	9 (11.2)	15.4	<0.001
	No	122 (75.3)	51 (62.2)	71 (88.8)		
Place of delivery of index child	Home	110 (67.9)	65 (79.3)	45 (56.2)	9.8	0.002
	Institution	52 (32.1)	17 (20.7)	35 (43.8)		
Wash salt before use[a]	No	136 (84.0)	75 (91.5)	61 (76.2)	6.96	0.008
	Yes	26 (16.0)	7 (8.5)	19 (23.8)		
Salt utilization	Add after cooking	37 (22.8)	7 (8.5)	30 (37.5)	19.3	<0.001
	Cook with food	125 (77.2)	75 (91.5)	50 (62.5)		
Use iodized salt	Yes	58 (35.8)	19 (23.2)	39 (48.8)	11.5	<0.001
	No	104 (64.2)	63 (66.8)	41 (51.2)		

Antenatal care

Lowland agro-ecological zone is represented by Babile District (Woreda) which is 560 km away from Addis Ababa in the eastern part of Ethiopia and midland agro-ecological zone is represented by Hintalo Wajirat and Endreta districts which are 683 and 773 km away from Addis Ababa in the northern part of Ethiopia. Lowland and midland zones were compared by unpaired *t* test and *p* values are shown

[a] In Ethiopia most households use crystal salt and during our survey we found that they wash it before use. Some of the households reported that they wash and grind the salt before use

more than that of the midland mother (28.6%; $X^2 = 10.1$, $p = 0.001$). A larger percentage of the midland mothers completed four focused ANC sessions (46.2%) compared to the lowland mothers (13.7%; $p < 0.001$); the proportion of contraceptive users was higher among the midland mothers than the lowland ones (70.0 vs. 39.0%), and the proportion of the mothers who had their own source of income was higher among the lowland compared to the midland mothers (37.8 vs. 11.2%). Similarly the proportion of households that used iodized salt in the previous 24 h was 35.8% with a significantly higher rate in midlands (Table 1).

The mean ages of the mothers and the children were 28.6 (SD ± 5.72) years and 13.44 (SD ± 4.91) months, respectively. Similarly, mean and standard deviation of serum zinc of mothers were 57.0 (22.93) whereas mean

Table 2 Descriptive indicators and correlation of the micronutrient and nutritional status of children (6–23 months) and their lactating mothers in two agro-ecological zones of rural Ethiopia

Variables	Children Mean (SD)	Mothers Mean (SD)	Correlation coefficients	*p* values
Serum ferritin (μg/l)	23.2 (24.31)	48.1 (36.25)	0.23	0.003
Haemoglobin (g/dl)	10.6 (1.62)[c]	13.3 (1.27)[3]	0.156	0.048
Serum zinc (µg/l)	55.8 (24.54)	57.0 (22.93)	0.349	<0.001
Under nutrition[a]	−1.57 (1.35)	19.2 (2.15)	0.215	0.006
Age[b]	13.4 (4.91)	28.6 (5.72)	–	–
MUAC (cm)	22.0 (1.58)	12.8 (1.12)	–	–
Height (cm)	71.9 (5.61)	159.7 (5.46)	–	–
Weight (kg)	8.3 (1.44)	48.9 (6.28)	–	–
DDS	2.6 (1.28)	3.1 (0.84)	–	–

MUAC mid-upper arm circumference (cm), *DDS* dietary diversity score

[a] Under nutrition is defined as stunting (calculated as length-for-age *Z* score <−2) for children and low BMI (<18.5 kg/m^2) in mothers

[b] Age is in months for children and in years for mothers

[c] Anaemia was defined as a haemoglobin concentration <11 g/dl (in children) and <12 g/dl (in mothers)

(SD) for children were 55.8 (24.54) µg/l, respectively. While the correlations between mothers and their children were low, they were statistically significant for serum ferritin ($p = 0.003$), zinc ($p < 0.001$) and haemoglobin ($p = 0.048$; Table 2).

Anaemia among mothers and children

The overall prevalence of anaemia among the mothers was 19.1%, whereas it was 52.5% among the children. The prevalence was higher among the lowland mothers (30.5%) compared to the midland mothers (7.5%; $p < 0.001$; Table 3). Prevalence was also higher among the 25–34 years of age mothers and among 12–17 months of age children compared to 15–24 years of age mothers and 18–23 months of age children (Table 4). There is statistically significant association between maternal and child anaemia in this study group ($X^2 = 39.16$, $p < 0.001$; Table 3).

Iron deficiency anaemia among mothers and children

The overall prevalence of iron deficiency among the mothers was 19.8%. However, the prevalence was higher in lowland mothers (35.4%) than in midland ones (3.8%) and this difference was statistically significant ($p < 0.001$). The prevalence of iron deficiency was higher among 25–34 years of age mothers (68.8%; Table 4). Similarly, overall prevalence of iron deficiency among children was 44.4%, with no marked difference between the agro-ecological zones (46.3% in lowland and 42.5% in midland; Table 3). The 18–23 months children were more iron deficient (37.5%) than 12–17 months children (31.9%; Table 4).

Iron and iron deficiency anaemia among mothers and children

Out of the 162 children, 29.6% had iron deficiency anaemia (IDA) (a combination of iron deficiency and anaemia). The highest prevalence of iron deficiency anaemia was found among the lowland children but was not statistically significant (Table 3).

Of the mothers, 10.5% had iron deficiency anaemia with prevalence of 19.5% in the lowlanders and 1.2% in the midlanders. This difference was statistically significant ($p < 0.001$). Similarly, there was a statistically significant association between the prevalence of iron deficiency anaemia among the mothers and their children ($X^2 = 18.5$, $p < 0.001$; Table 3).

Table 4 shows data on iron status of both the lactating mothers and their children by age. Iron deficiency was most common among the children 18–23 months of age (37.5%). As the age of the children increased, the prevalence of iron deficiency increased. However, the level of iron deficiency anaemia was highest (35.4%) among 12–17 months of age children and lowest among 6–11 months of age. Iron deficiency without anaemia was highest among the children 6–11 months of age (47.2%). Iron deficiencies, both with and without anaemia, were more prevalent among 25–34 years of age of the mothers.

Salt utilization

Among the households under study, 35.8% of them used iodized salt on the previous night of the survey. In Ethiopia most households use crystal salt. Some of the households reported that they washed and ground the salt. Regarding

Table 3 Micronutrients and nutritional status of mothers and children (6–23 months) by agro-ecological zones in rural Ethiopia

Variables	Overall children *N* (%)	Overall mothers *N* (%)	X^2	*p* value	Children				Mothers			
					Lowland *N* (%)	Midland *N* (%)	X^2	*p* value	Lowland *N* (%)	Midland *N* (%)	X^2	*p* value
Ferritin[a]												
Non-deficient	90 (55.6)	130 (80.2)	1.00	1.00	44 (53.7)	46 (57.5)	1.0	0.640	53 (64.6)	77 (96.2)	1.0	
Deficient	72 (44.4)	32 (19.8)	22.66	<0.001	38 (46.3)	34 (42.5)	0.24		29 (35.4)	3 (3.8)	24.7	<0.001
Iron deficiency anaemia[b]												
Yes	48 (29.6)	17 (10.5)	18.50	<0.001	26 (31.7)	22 (27.5)	0.34	0.608	16 (19.5)	1 (1.2)	14.4	<0.001
No	114 (70.4)	145 (89.5)	1.00	1.00	56 (68.3)	58 (72.5)	1.00		66 (80.5)	79 (98.8)	1.00	
Anaemia[c]												
Non-anaemic	77 (47.5)	131 (80.9)	1.00	1.00	35 (42.7)	42 (52.5)	1.0		57 (69.5)	74 (92.5)	13.84	<0.001
Anaemic	85 (52.5)	31 (19.1)	39.16	<0.001	47 (57.3)	38 (47.5)	1.56	0.2	25 (30.5)	6 (7.5)	1.00	
Normal zinc value	53 (32.7)	45 (27.8)	1.00	1.00	22 (26.8)	31 (38,8)	1.00		4 (4.9)	41 (51.2)	1.00	
Zinc deficiency[d]	109 (67.3)	117 (72.2)	0.94	0.33	60 (73.2)	49 (61.2)	2.61	0.1	78 (95.1)	39 (48.8)	43.4	<0.001
Maternal BMI												
<18.5	–	68 (42.0)	–	–	–	–	–	–	33 (40.2)	35 (43.8)	0.204	0.750
≥18.5	–	94 (58.0)	–	–	–	–	–	–	49 (59.8)	45 (56.2)	1.00	
Stunted												
LAZ < −2	58 (35.8)	–	–	–	31 (37.8)	27 (33.8)	0.29	0.626	–	–	–	–
LAZ > −2	104 (64.2)				51 (62.2)	53 (66.2)	1.00					
Wasted												
WLZ < −2	21 (13.0)	–	–	–	10 (12.2)	11 (13.8)	0.087	0.818	–	–	–	–
WLZ > −2	141 (87.0)				72 (87.8)	69 (86.2)	1.00					
Underweight												
WAZ < −2	37 (22.8)	–	–	–	18 (22.0)	19 (23.8)	0.74	0.852	–	–	–	–
WAZ > −2	125 (77.2)	–	–	–	64 (78.0)	61 (76.2)	1.00		–	–	–	–

LAZ length-for-age *Z* score, *WAZ* weight-for-age *Z* score, *WLZ* weight-for-length *Z* score

[a] Iron deficiency is defined as a serum ferritin concentration <15 µg/l for mothers and <12 µg/l children

[b] Iron deficiency anaemia was defined as presence of anaemia and a serum ferritin concentration <15 µg/l for mothers and <12 µg/l children

[c] Anaemia was defined as a haemoglobin concentration <11 g/dl (in children) and <12 g/dl (in mothers)

[d] Zinc deficiency was defined as serum zinc less than 65 µg/l for children and less than 66 µg/l in mothers

Table 4 Micronutrients and nutritional status of mothers and children by age in rural Ethiopia

Variables	Haemoglobin and Ferritin					Zinc	LAZ	WLZ	WAZ
	Iron deficient[a] N (%)	Iron deficiency without anaemia N (%)	Iron deficiency anaemia[b] N (%)	Other causes of anaemia N (%)	Total anaemia N (%)	Zinc deficient[c] N (%)	Z score < −2	Z score < −2	Z score < −2
Children age (months)									
6–11	22 (30.6)	17 (47.2)	15 (31.2)	7 (28.0)	32 (37.6)	40 (36.7)	15 (25.9)	1 (4.8)	9 (24.3)
12–17	23 (31.9)	15 (41.7)	17 (35.4)	6 (24.0)	32 (37.6)	42 (38.5)	26 (44.8)	12 (57.1)	17 (45.9)
18–23	27 (37.5)	4 (11.1)	16 (33.3)	12 (48.0)	21 (24.7)	27 (24.8)	17 (29.3)	8 (38.1)	11 (29.7)
Total	72 (44.4)	36 (22.2)	48 (29.6)	25 (15.4)	85 (52.5)	109 (67.3)	58 (35.8)	21 (13.0)	37 (22.8)
Mothers age (months)							BMI < 18.5	MUAC < 22	
15–24	5 (15.6)	1 (7.1)	3 (17.6)	2 (13.3)	4 (12.9)	21 (63.6)	15 (22.1)	20 (22.5)	–
25–34	22 (68.8)	8 (57.1)	12 (70.6)	10 (66.7)	20 (64.5)	70 (74.5)	40 (58.8)	49 (55.1)	–
35–49	5 (15.6)	5 (35.7)	2 (11.8)	3 (20.0)	7 (22.6)	26 (74.3)	13 (19.1)	20 (22.5)	–
Total	32 (19.8)	14 (8.6)	17 (10.5)	15 (9.3)	31 (19.1)	117 (72.2)	68 (42.2)	89 (45.1)	–

LAZ length-for-age *Z* score, *WAZ* weight-for-age *Z* score, *WLZ* weight-for-length *Z* score, *BMI* body mass index calculated as weight in kg/height in metre^2 (kg/m^2), *MUAC* mid-upper arm circumference in cm

[a] Iron deficiency is defined as a plasma ferritin concentration <15 µg/l for mothers and <12 µg/l children

[b] Iron deficiency anaemia was defined as anaemia (haemoglobin concentration <110 mg/dl in children and <120 mg/dl in mothers) and a plasma ferritin concentration <15 µg/l for mothers and <12 µg/l children

[c] Zinc deficiencies were defined as plasma zinc less than 65 µg/l for children and less than 66 µg/l in mothers

the methods of using the salt, 26% of the household reported washing the salt before using for cooking and about 77.2% of the households reported that they cook the salt in the food. These data highlight the need to increase awareness about proper utilization of iodized salt in the community.

Zinc deficiency anaemia among mothers and children

The prevalence of low serum zinc concentration was 67.3% among the children and 72.2% among the mothers. Among children the prevalence in both agro-ecological zones was statistically similar (73.2% in lowland and 61.2% in midland). However, there was a statistically significant difference between the zones in the prevalence of low zinc concentration among the mothers ($X^2 = 43.4$, $p < 0.001$), with very high prevalence (95.1%) among lowland mothers (Table 3).

Undernutrition among mothers and children

Thirteen percentage of children were wasted, 22.8% were underweight and 35.8% were stunted. There was no statistical difference in these indices between lowland and midland regions (Table 3). In all three anthropometric measurements, the highest malnutrition was recorded at 12–17 months of age (Table 4). Similarly, IDA and zinc deficiency were most prevalent among this age group while iron deficiency was highest among 18–23 months age group. As measured by BMI (<18.5 kg/m^2), 42.2% of the mothers were malnourished, and the most affected age group was 25–34 years (Table 4). Similarly, based on MUAC, 45.1% of mothers had MUAC less than 22 cm (malnourished). Maternal wasting (low BMI), and all forms of micronutrient deficiencies analysed in this study were most prevalent among 25–34 year age group indicating the vulnerability of this age group (Table 4).

Multiple micronutrient deficiencies of mothers and children

This study showed that 32.7% of the children were deficient in two micronutrient biomarkers (serum ferritin and zinc) whereas 46.3% of children were deficient in one of the micronutrient biomarkers. Deficiencies of two micronutrients in children were statistically associated with the mothers' micronutrient status ($p < 0.01$) but not with the agro-ecological zones. Similarly, 19.1 and 53.7% of the mothers were deficient in two, and one micronutrient biomarkers, respectively, and there were statistically significant associations between the multiple micronutrient deficiencies and the agro-ecological zones among mothers ($p < 0.001$; Table 5).

Table 5 Zinc and iron deficiencies in combination among lactating mothers and their children (6–23 months) by agro-ecological zones in rural Ethiopia

Variables	Mother and children			Children			Mothers		
	Overall children *N* (%)	Overall mothers *N* (%)	*p* value	Lowland *N* (%)	Midland *N* (%)	*p* value	Lowland *N* (%)	Midland *N* (%)	*p* value
Deficient in 2	53 (32.7)	31 (19.1)	0.01	31 (37.8)	22 (27.5)	0.19	28 (34.1)	3 (3.8)	<0.001
Deficient in 1	75 (46.3)	87 (53.7)	0.69	36 (43.9)	39 (48.8)	0.71	51 (62.2)	36 (45.3)	<0.001
Non-deficient	34 (21.0)	44 (45.1)		15 (18.3)	19 (23.8)		3 (3.7)	41 (51.2)	

Iron deficiency is defined as a serum ferritin concentration <15 µg/l for mothers and <12 µg/l children

Zinc deficiency was defined as serum zinc less than 65 µg/l for children and less than 66 µg/l in mothers

Deficient in both means the mother/child is deficient in both zinc and ferritin while deficient in one means the mother/child is deficient either in zinc or ferritin

Table 6 Relationships between zinc and iron deficiencies among lactating mothers and their children (6–23 months) in rural Ethiopia

Variables	Categories	Mothers		*X* (*p* value)
		Yes *N* (%)	No *N* (%)	
Children				
Deficient in two micronutrient	Yes	16 (9.9)	37 (22.8)	5.17 (0.02)
	No	15 (9.3)	82 (50.6)	
Deficient in one micronutrient	Yes	65 (40.1)	10 (6.2)	61.03 (<0.001)
	No	22 (13.6)	65 (40.1)	

Relationship between micronutrient deficiencies in mother and child pairs

This study showed that among 53 children and 31 mothers with multiple micronutrient deficiencies, 16 (9.9%) of the mother and child pairs were deficient in both micronutrients. Additionally, 65 (40.1%) of the mother and child pairs were deficient in a single micronutrient (Table 6).

Concurrent micronutrient deficiencies of mothers and children

Among mothers with iron deficiency, 81.2, 56.2 and 68.8% of their children were deficient in zinc, ferritin and anaemic, respectively. Similarly among low zinc status mothers, 75.2, 45.3 and 55.6% of their children had low serum zinc, ferritin and anaemic, respectively. Among undernourished mothers, 41.2% of their children were stunted, 67.6% had low serum zinc and 60.3% of them were anaemic (Table 7).

Dietary habits of mothers and children

The mean and standard deviation for dietary diversity score was 3.1 (0.85) for lactating mothers and 2.6 (1.3) for children. Only 6.8% of mothers and 21% of children achieved

Table 7 Concurrent micronutrient deficiencies among lactating mothers and their children (6–23 months) in two agro-ecological zones of rural Ethiopia

Mother deficiencies	Children deficiencies				
	Zinc *N*/total (%)	IDA[a] *N*/total (%)	Ferritin *N*/total (%)	Anaemia *N*/total (%)	Undernutrition[b] *N*/total (%)
Iron deficient[c]	26/32 (81.2)	26/31 (81.2)	18/32 (56.2)	22/32 (68.8)	13/32 (40.6)
Anaemia[d]	24/31 (77.4)	13/31 (41.9)	14/31 (45.2)	23/31 (74.2)	8/31 (25.8)
Undernutrition[b]	46/68 (67.6)	26/68 (38.2)	34/68 (50.0)	41/68 (60.3)	28/68 (41.2)
Zinc[e]	88/117 (75.2)	38/117 (32.5)	53/117 (45.3)	65/117 (55.6)	46/117 (39.3)

[a] IDA, Iron deficiency anaemia was defined as anaemia and a serum ferritin concentration <15 µg/l for mothers and <12 µg/l children

[b] Undernutrition is defined as stunting (calculated as length-for-age *Z* score <−2) for children and low BMI (<18.5 kg/m^2) in mothers

[c] Iron deficiency is defined as a plasma ferritin concentration <15 µg/l for mothers and <12 µg/l children

[d] Anaemia was defined as a haemoglobin concentration <110 mg/dl (in children) and <120 mg/dl (in mothers)

[e] Zinc deficiency was defined as plasma zinc less than 65 µg/l for children and less than 66 µg/l in mother

Table 8 Dietary diversity of mothers and children in rural Ethiopia

Variables	Mothers	Children
Dietary diversity score (mean and SD)	3.1 (0.85)	2.6 (1.3)
% achieving adequate dietary diversity	6.8	21
% consumed zinc inhibitors in previous 24 h	82.1	91.9
% consumed flesh foods in previous 24 h	2.5	3.7
% consumed pre-vit A-rich foods in previous 24 h	64.8	61.1
% consumed tea/coffee < 4 times in a week	24.7	61.1[a]
% drank milk in previous 24 h	29.0	42.6

[a] In lowland agro-ecological zone there is a behaviour of feeding children with tea or adding tea/Hoja (coffee with added milk) when mashing food

minimum dietary diversity in the 24 h preceding the survey date. Consumption of foods with potential to inhibit zinc bioavailability (bread, millet, pulses, soybean and drinking tea) by both groups was high as 82.1% of mothers and 91.9% of children consumed these foods in the 24 h before the survey. Only 2.5% of mothers and 3.7% of children consumed flesh foods (Table 8).

Factors associated with selected micronutrient deficiencies

Body mass index of the mother, household utilization of iodized salt, family planning utilization, de-worming tablets in the past three months, and maternal and paternal education and occupation did not show statistically significant associations with maternal ferritin in the bivariate models. These variables also had non-significant association with maternal ferritin in multivariate models and, therefore, were removed from the final model. Maternal zinc status, drinking water, women dietary diversity score, frequency of drinking coffee/tea in a week and maternal haemoglobin were significantly associated with ferritin status of the mothers and included in the multivariate model.

As the maternal zinc level increases by one unit, maternal ferritin increased significantly ($\beta = 0.34$, $p = 0.005$). Those mothers who used protected water sources had higher levels of maternal ferritin compared to those who used unprotected water ($\beta = 18.4$, $p = 0.001$), and mothers who drank coffee/tea more than four times had significantly lower levels of ferritin than those who drank coffee/tea less than four times in a week ($\beta = -15.7$, $p = 0.003$; Table 9).

We found that child ferritin level is associated with child haemoglobin level. Similarly, as maternal ferritin level increases, the ferritin level of the children also significantly increases ($\beta = 0.13$, $p = 0.014$). As age of the children increased the zinc level tended to decrease but was not statistically significant in multivariate model analysis. Child and maternal zinc status had no association with child ferritin level. In model three, maternal zinc is associated with child zinc status ($\beta = 0.38$, $p < 0.001$), but eating foods that contain zinc bioavailability inhibitors was not significant in multivariate analysis (Table 9).

Table 9 Selected predictors of micronutrient deficiency among mothers and children in rural Ethiopia

Variables	Bivariate model		Multivariate model	
	β (95% CI)	p values	β (95% CI)	p values
Model 1: Maternal ferritin				
Maternal zinc	0.62 (0.34, 0.85)	<0.001	0.34 (0.10, 0.57)	0.005
Source of drinking water	28.72 (18.3, 39.2)	<0.001	18.4 (7.4, 29.4)	0.001
Women dietary diversity score	6.23 (−0.39, 12.9)	0.065	3.5 (−2.3, 9.4)	0.236
Frequency of drinking tea/coffee in week	−25.6 (−36.4, −14.7)	<0.001	−15.7 (−26.1, −5.4)	0.003
Model 2: Child ferritin				
Maternal ferritin	0.15 (0.052, 0.26)	0.003	0.13 (0.026, 0.23)	0.014
Child age	−0.71 (−1.5, 0.52)	0.068	−0.6 (−1.4, 0.13)	0.10
Model 3: Child zinc				
Maternal zinc	0.37 (0.22, 0.53)	<0.001	0.38 (0.23, 0.54)	<0.001
Eat zinc bioavailability inhibitors	2.8 (−2.1,3.1)	0.09	−1.2 (−10.6, 8.1)	0.79
Model 4: Maternal zinc				
Maternal ferritin	0.25 (0.16, 0.34)	<0.001	0.15 (0.057, 0.25)	0.002
Source of drinking water	19.7 (13.2, 26.2)	<0.001	14.1 (7.3, 20.8)	<0.001
Flesh food	17.0 (6.7, 31.4)	0.049	18.0 (1.7, 34.4)	0.031
BMI of the mothers	−1.9 (−3.2, −0.29)	0.022	−1.8 (−3.2, −0.38)	0.013
Frequency of drinking tea/coffee in week	−10.6 (−17.3, 5)	0.04	−3.9 (−10.7, 1.9)	0.063

Maternal zinc is significantly associated with maternal ferritin, source of drinking water, consuming flesh food in the previous 24 h and BMI of the mother. Frequency of drinking tea/coffee in the previous week was not significant. Mothers who consumed flesh food in the 24 h preceding the survey had significantly higher zinc status ($\beta = 18.0$, $p = 0.031$). Maternal ferritin ($\beta = 0.15$, $p = 0.002$) and protected source of drinking water ($\beta = 14.1$, $p < 0.001$) showed significant association with maternal zinc level (Table 9).

Discussion

This study demonstrated significant association between maternal micronutrient status and child nutritional status independent of maternal age, children's age and sex and socio-demographic conditions. This association may be due to the shared environment which could impact a child's nutritional status through a number of factors including breastfeeding practices, access to quality foods and health care resources. In general, the nutritional status of mothers and their children was poorer in the lowland regions compared to the midland zone of rural Ethiopia.

The significant interrelationship between maternal and child nutritional status is similar to that seen between mothers and their children in earlier studies from Ethiopia and Bangladesh [36, 37]. But in this study the correlation is weak. The nutrition Collaborative Research Support Program (CRSP) studies reported significant positive correlations between maternal lean mass and infant weight and length, and between maternal BMI and infant length at 3–6 months post-partum. These studies demonstrate the need for nutritional assessments and interventions that encompass both mothers and children in future public health initiatives. The population in the present study was mainly rural; however, both agro-ecological zones have their own traditional habits and diets. The cultural and the traditional feeding habits in the two agro-ecological zones have previously been reported [35].

In this study, 67.3% of the mothers and 72.2% of the children were zinc deficient. This prevalence is lower than reported in studies conducted in Indonesia and Mexico [38, 39]. The prevalence of low maternal zinc status in our study was similar to that reported in a study conducted in Gondar [13] and slightly lower than reported in another study among pregnant women in southern Ethiopia [40].

Anaemia was more prevalent among the children (52.5%) than among their mothers (19.1%) and in the lowland compared to the midland zone. This finding is in contrast to a study conducted in Indonesia where higher prevalence of anaemia was reported in mothers (50%) than in children (17%). There is a statistically significant association between anaemia among mothers and their children ($p < 0.001$). The prevalence of IDA was also higher among children (29.5%) than the mothers (10.5%). The prevalence of IDA in our study group is lower than reported in other studies in Ethiopia [15, 16, 41].

Another noteworthy finding is the presence of multiple micronutrient deficiencies. When compared to children without anaemia, children with anaemia had a higher prevalence of low zinc status (68.7 vs 87.1%). Similarly, children with low serum ferritin statuses are more deficient in zinc compared to children without ferritin deficiency. Similar findings are apparent in the mothers. The co-occurrence of both zinc and ferritin deficiencies in the children was higher than their mothers showing that micronutrient deficiency is a serious nutritional issue among the children. The high levels of zinc and iron deficiency also suggest that there could be broader micronutrient deficiencies in the study population but we did not assess other micronutrients due to financial constraints. This calls for more comprehensive and preventive approaches or interventions—whether food based, supplement based or fortification based—to alleviate this serious public health issue.

Zinc, iron and anaemia levels of the mothers were significantly associated with corresponding parameters in their children ($p < 0.001$). Additionally, there was a statistically significant association between mothers and their respective children regarding the co-occurrence of deficiencies of all three or two micronutrient biomarkers ($p < 0.001$). This suggests that the nutritional deficiencies of the lactating mothers and their children are highly inter-correlated. An Indonesian study also reports a similar finding [38]. In lactating mothers, there were also statistically significant differences ($p < 0.001$) in micronutrient deficiency between the lowland and the midland agro-ecological zones, but these were not observed in children. This may be due to the feeding habits differences in both communities [35]. A recent study in Cambodia reported a significant but weak association between maternal haemoglobin and child's haemoglobin status [42]. Based on the odds ratio, the odds for children aged 6–12 months being anaemic were 1.77 times higher if their mother was anaemic. Children aged 12–24 months had a 1.82 times higher chance of being anaemic if their mother was anaemic.

This analysis adds to the literature on maternal nutritional status in rural communities in low income nations. It demonstrates the presence of acute undernutrition as shown by the low BMI values among mothers in the study's population. It contributes to the understanding of determinants of maternal nutrition in rural Ethiopia. The presence of interrelationship between maternal nutritional measures and child nutritional status (Table 6) stresses the importance of addressing maternal nutritional status with the aim of improving both maternal and child health outcomes.

Dietary diversity of mothers and children 6–23 months old in this study is very low indicating that there are poor feeding practices in the community. This study was conducted in the postharvest season at a time of good agricultural production in Ethiopia and when no drought affected these communities. Additionally, it is expected that during the postharvest season farm income will increase which may in turn increase consumption and purchase of adequate food. However, it is also expected that access to fruit may decrease during the postharvest season as its production is quite seasonal and it is not found in local markets.

In addition to poor dietary diversity in this study population, the proportion of children and mothers who consume foods (e.g. cereals) rich in inhibitors of zinc bioavailability (phytates) was very high, which may be one of the factors contributing to zinc deficiency. Consumption of flesh food (rich in iron and zinc) was exceptionally low, whereas consumption of foods that can interfere with iron absorption (e.g. coffee) was high.

In this study, we found that mothers who drink water from protected sources have significantly lower deficiency of iron and zinc. Consumption of unprotected water may expose the mothers to loss of nutrients from the body as a result of diarrhoea. However, this needs further investigation. It has also been reported that in India, poor environmental sanitation, unsafe drinking water and inadequate personal hygiene are factors affecting anaemia prevalence [43].

One of the limitations of this study is that it did not assess energy and nutrient intake quantitatively, because it used a qualitative 24-h recall data. The other possible limitation is recall bias associated with maternal memory and other response variables. We were not able to test creatinine reactive protein (CRP) as a measure of acute infection or inflammation responses due to financial reasons and absence of required reagents at national level during this study. However, bloods were collected from apparently healthy individuals who self-reported no ill health prior to the study. No medical examination was conducted on study participants to assess health status due to financial constraints.

Conclusion

This study showed that anaemia, low serum iron and zinc statuses are very prevalent micronutrient deficiencies among lactating mothers and their children <24 months in rural Ethiopia. Deficiencies among the lactating mothers correlated significantly with deficiencies in their children suggesting that micronutrient deficiency is intergenerational, even though the mechanisms involved have not yet been explained adequately. Many of the low iron status mothers and children were also had low zinc status, suggesting that there is an association between iron and zinc status. The fact that we found multiple micronutrient deficiencies within this study population indicates the need to establish effective preventive public health nutrition programs. These programs need to focus on nutrition education regarding the importance of improving dietary diversity and, in particular, adding animal source food rich in iron and zinc in the daily diet.

Acknowledgements We would like to acknowledge Irish Aid for sponsoring Ph.D. studies as part of Agridiet project and the research work included in this paper. Kedir Teji would also like to thank the entire Agridiet team for their great guidance and support during his stay in Cork. We would like to express our sincere gratitude to Haramaya University, all participants of the study and data collectors.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

References

1. FAO/WHO (1992) International conference on nutrition. World declaration and plan of action. FAO, Rome
2. Kent JC (2007) How breastfeeding works. J Midwifery Womens' Health 52:564–570. doi:10.1016/j.jmwh.2007.04.007
3. Allen LH (1993) The nutrition CRSP: what is marginal malnutrition, and does it affect human function? Nutr Rev 51:255–267
4. Christian P, West KP Jr (1998) Interactions between zinc and vitamin A: an update. Am J Clin Nutr 68:435S–441S
5. Whittaker P (1998) Iron and zinc interactions in humans. Am J Clin Nutr 68:442S–446S
6. Singh M (2004) Role of micronutrients for physical growth and mental development. Indian J Pediatr 71:59–62
7. Bitanihirwe BK, Cunningham MG (2009) Zinc: the brain's dark horse. Synapse 63:1029–1049
8. Solomons NW, Jacob R (1981) Studies on the bioavailability of zinc in humans: effects of heme and nonheme iron on the absorption of zinc. Am J Clin Nutr 34:475–482
9. Hurtado EK, Claussen AH, Scott KG (1999) Early childhood anemia and mild or moderate mental retardation. Am J Clin Nutr 69:115–119
10. Idjradinata P, Pollitt E (1993) Reversal of developmental delays in iron-deficient anemic infants treated with iron. Lancet 341(8836):1–4
11. Brown KH (1998) Effect of infections on plasma zinc concentration and implications for zinc status assessment in low-income countries. Am J Clin Nutr 68:425S–429S
12. Brown KH, Wuehler SE, Peerson JM (2001) The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency. Food Nutr Bull 22:113–125
13. Umeta M, West CE, Haidar J, Deurenberg P, Hautvast JG (2000) Zinc supplementation and stunted infants in Ethiopia: a randomised controlled trial. Lancet 355:2021–2026
14. A2Z, FANTA project (2006) Maternal anemia: a preventable killer. http://www.aed.org/Publications/upload/FANTAanemia2006.pdf. Accessed on May 2014
15. Kalaivani K (2009) Prevalence & consequences of anaemia in pregnancy. Indian J Med Res 130:627–633

16. Kassu A, Yabutani T, Mulu A, Tessema B, Ota F (2008) Serum zinc, copper, selenium, calcium, and magnesium levels in pregnant and non-pregnant women in Gondar, Northwest Ethiopia. Biol Trace Elem Res 122(2):97–106
17. Gebremedhin S (2011) Prevalence of prenatal zinc deficiency and its association with socio-demographic, dietary and health care related factors in Rural Sidama, Southern Ethiopia: a cross-sectional study. BMC Public Health 11:1
18. Umeta M, Haidar J, Demissie T, Akalu G, Ayana G (2008) iron deficiency anaemia among women of reproductive age in nine administrative regions of Ethiopia. Ethiop J Health Dev 22:252–258
19. Haidar J, Muroki NM, Omwega AM, Ayana G (2003) Malnutrition and iron deficiency in lactating women in urban slum communities from Addis Ababa, Ethiopia. East Afr Med J 80:191–194
20. Woldie H, Kebede Y, Tariku A (2015) Factors associated with anemia among children aged 6–23 months attending growth monitoring at Tsitsika Health Center, Wag-Himra Zone, Northeast Ethiopia. J Nutr Metab 2015. doi:10.1155/2015/928632
21. EDHS (2012) Central Statistical Authority, ORC Macro: Ethiopia demographic and health survey. CSA and ORC, Addis Ababa, Ethiopia and Calverton, Maryland, USA
22. Gebreegziabiher G, Etana B, and Niggusie D (2014) Determinants of anemia among children aged 6–59 months living in Kilte Awulaelo Woreda, Northern Ethiopia J Anaemia 2014:245870. doi:10.1155/2014/245870
23. IZiNCG (2004) Assessment of the risk of zinc deficiency in populations and options for its control. Food Nutr Bull 25(1 Suppl):S99–S203
24. International nutritional anaemia consultative group (INACG) (1979) Iron deficiency in infants and child hood. Nutrition Foundation, New York
25. WHO (2001) Iron deficiency anaemia: assessment, prevention and control, a guide for programme managers. World Health Organization, Geneva
26. Nkrumah B, Nguah S, Sarpong N, Dekker D, Idriss A et al (2011) Hemoglobin estimation by the HemoCueH portable hemoglobin photometer in a resource poor setting. BMC Clin Pathol 11:1
27. WHO (2011) Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Vitamin and Mineral Nutrition Information System Geneva, World Health Organization (WHO/NMH/NHD/MNM/111)
28. Iyengar GV, Woittiez JRW, Subramanian KS (1998) Element analysis of biological samples: principles and practice. CRC Press, Boca Raton
29. World Health Organization Multicentre Growth Reference Study Group (2006) WHO child growth standards based on length/height, weight and age. Acta Paediatr 450:76S–85S
30. WHO (2009) Child growth standards: growth velocity based on weight, length and head circumference: methods and development. World Health Organization, Geneva, p 242
31. Cogill B (2001) Anthropometric indicators measurement guide. Food and Nutrition Technical Assistance Project, Academy for Educational Development, Washington DC
32. WHO, United Nations Children's Fund United States, Agency for International Development, UC DAVIS, and IFPRI (2010) Indictors for assessing infant and young child feeding practices part III. WHO, Geneva
33. Arimond M, Ruel MT (2004) Dietary diversity is associated with child nutritional status: evidence from 11 demographic and health surveys. J Nutr 134:2579–2585
34. Roba KT, O'Connor TP, Belachew T, O'Brien NM (2016) Infant and Young Child Feeding (IYCF) practices among mothers of children aged 6–23 months in two agro-ecological zones of rural Ethiopia. Int J Nutr Food Sci 5:185–194
35. Roba KT, O'Connor TP, Belachew T, O'Brien NM (2015) Seasonal variation in nutritional status and anaemia among lactating mothers in two agro-ecological zones of rural Ethiopia: a longitudinal study. Nutrition 31:1213–1218
36. Girma W, Genebo T (2002) Determinants of nutritional status of women and children in Ethiopia. ORC Macro, Calverton
37. Silveira KBR, Alves JFR, Ferreira HS, Sawaya AL, Florêncio TMMT (2010) Association between malnutrition in children living in favelas, maternal nutritional status, and environmental factors. J Pediatr 86:215–220
38. Dijkhuizen MA, Wieringa FT, West CE, Muherdiyantiningsih Muhilal (2001) Concurrent micronutrient deficiencies in lactating mothers and their infants in Indonesia. Am J Clin Nutr 73:786–791
39. Villalpando Salvador, García-Guerra A, Ramírez-Silva CI, Mejía-Rodríguez F, Matute G et al (2003) Iron, zinc and iodide status in Mexican children under 12 years and women 12–49 years of age. A probabilistic national survey. Salud Pública de México 45:S520–S529
40. Gibson RS, Abebe Y, Stabler S et al (2008) Zinc, gravida, infection and iron, but not vitamin B-12 or folate status, predict hemoglobin during pregnancy in Southern Ethiopia. J Nutr 138:581–586
41. Haidar J (2010) Prevalence of anaemia, deficiencies of iron and folic acid and their determinants in Ethiopian women. J Health Popul Nutr 28:359–368
42. Reinbott A, Jordan I, Herrmann J, Kuchenbecker J, Kevanna O, Krawinkel MB (2016) Role of breastfeeding and complementary food on hemoglobin and ferritin levels in a Cambodian cross-sectional sample of children aged 3 to 24 months. PLoS ONE. doi:10.1371/journal.pone.0150750
43. Baranwal A, Baranwal A, Roy N (2014) Association of household environment and prevalence of anemia among children under-5 in India. Front Public Health 2:196. doi:10.3389/fpubh.2014.00196