Original Article

Establishing desirable fortificant levels for calcium, iron and zinc in foods for infant and young child feeding: examples from three Asian countries

Michelle M. Gibbs*, Alicia L. Carriquiry[†], Mario V. Capanzana[‡] and Rosalind S. Gibson**Department of Human Nutrition, University of Otago, Dunedin, New Zealand, [†]Department of Statistics, Iowa State University, Ames, Iowa, USA, and[‡]Food and Nutrition Research Institute, Department of Science and Technology, Bicutan, Taguig, Metro Manila, Philippines

Abstract

We used the World Health Organization's recommended procedures to establish desirable fortificant levels for three problem micronutrients in children's diets, based on dietary data collected earlier from Filipino ($n = 1374$; 6–36 months), Mongolian ($n = 179$; 12–36 months) and Cambodian ($n = 177$; 12–36 months) children. Prevalence of inadequate and excessive intakes of calcium and zinc (via cut-point method) and iron (via full-probability approach) was assessed after adjusting usual intake distributions with PC-SIDE using internal or external within-person variances from Filipino (calcium and iron) and US National Health And Nutrition Examination Survey III (zinc) national surveys. Fortificant levels were determined by repositioning usual intake distributions so that the 2.5th percentile of the targeted populations equalled the estimated average requirement (calcium, zinc) or so that full-probability prevalence was no larger than 2.5% (iron). Prevalence of inadequate intakes was $\geq 70\%$ for calcium and iron, except Filipino infants (30% for Ca) and Cambodian toddlers (41% for Fe); but $< 1\%$ for zinc for toddlers in Mongolia and 20% in Cambodia. Prevalence of excessive intakes was $< 1\%$ for zinc, calcium and iron, except for Mongolian toddlers (11% for Zn). Desirable fortificant levels, although apparently negligible for zinc, were 530–783 mg for calcium and 10.8–22.8 mg for iron (per 100 g). Fortificant levels can be estimated from 24-h recalls, preferably by applying internal within-person variances. Fortification with calcium and iron was necessary, but seemingly not for zinc, despite a high prevalence of low serum zinc, suggesting the need for better defined cut-offs for population risk of zinc deficiency based on dietary zinc intake and/or serum zinc.

Keywords: micronutrient fortificants, Asian children, PC-SIDE, estimated average requirements, within-person variation.

Correspondence: Rosalind S. Gibson, Department of Human Nutrition, University of Otago, Union Street, PO Box 56, Dunedin 9015, New Zealand. E-mail: rosalind.gibson@otago.ac.nz

Introduction

The period between birth and 2 years of age is a critical time point for the prevention of malnutrition [World Health Organization (WHO) 2004]. After 2 years of age, the adverse consequences of malnutrition are often irreversible (Martorell *et al.* 1994) and may lead to permanent stunting and health impairments, with the potential to affect the health, educa-

tional and economic status of future generations (Victora *et al.* 2008). To prevent malnutrition during this vulnerable period, infants and toddlers must be fed safe and nutritionally adequate foods. In low-income countries in Asia, the traditional foods fed to infants and toddlers are based on cereals and legumes, often with a low micronutrient density and high-phytate content, a potent inhibitor of mineral absorption (Gibson *et al.* 1998). As a result, they often

fail to meet infant's micronutrient requirements. Of the micronutrient deficits, the most notable are for iron, zinc and calcium, despite increases in the efficiency of absorption when dietary intakes and status are low [Institute of Medicine (IOM) 1997, 2001]. Furthermore, deficits in these three micronutrients, unlike those for energy, are not readily overcome by using household strategies such as dietary diversification and modification (Gibson *et al.* 1998; WHO/UNICEF 1998). Instead, alternative strategies are needed to ensure the micronutrient adequacy of foods for infants and toddlers in low-income Asian countries.

In industrialised countries, manufactured cereal-based foods for infants and toddlers are frequently fortified with iron and, hence, provide a major dietary source of non-haem iron (Fox *et al.* 2006). Furthermore, consumption of such iron-fortified foods has frequently reduced the prevalence of iron-deficiency anaemia and storage iron depletion among young children (Ferguson & Darmon 2007; Dewey & Adu-Afarwuah 2008). Indeed, in some cases, iron-fortified cereals have been as efficacious as medicinal iron supplements for improving iron status (Ziegler *et al.* 2009). The demand for manufactured and fortified foods of high nutrient quality that are acceptable, affordable, easy to prepare and safe for infant and young child feeding is growing in low-income countries in Asia and elsewhere as urbanisation increases (Huffman *et al.* 2000). Moreover, the WHO advocates the consumption of fortified foods in low-income countries in their guiding principles for both breastfed and non-breastfed children (WHO 2004, 2005). Unfortunately, these manufactured foods, even when fortified, may have micronutrients at levels that fail to

meet the high nutrient requirements of infants and young children (López De Romaña 2000; Lutter 2000). In an effort to overcome this problem, the World Health Organization/Food and Agriculture Organization (WHO/FAO) (2006) have published guidelines endorsing the Institute of Medicine (IOM 2003) approach for establishing fortificant levels for foods for infant and young child feeding. The guidelines aim to achieve a desirably low prevalence of inadequate micronutrient intakes (e.g. 2–3%) in the target group. The approach requires individual-level data on dietary intakes for the targeted populations that can be used to determine the distribution of usual nutrient intakes, the actual prevalence of inadequate intakes, and then the amount of each fortificant needed to yield a low prevalence of inadequate and excessive intakes. Hence, valid data are needed on the nutrient composition of local foods, usual nutrient intakes (i.e. from weighed records or 24-h recalls), and the estimated average requirements (EARs) and tolerable upper levels (ULs) for each nutrient of interest. However, individual-level intake data require a second observation of dietary intakes on at least a subsample of the population so that an adjustment can be made to the observed distributions of intakes based on 1 day to remove the variability introduced by day-to-day variation in nutrient intakes within an individual (i.e. to remove the within-person variation). Such an adjustment can be performed using a statistical approach developed by Nusser *et al.* (1996). The adjustment process provides estimates of the distribution of usual intakes for a specified age- and gender-specific subgroup. In practice, there is a paucity of such individual-level dietary intake data from infants and toddlers from low-income countries

Key messages

- Fortificant levels can be estimated from 24-h recalls using the WHO's recommended procedure preferably by applying internal within-person variance estimates.
- Desirable fortificant levels for calcium and iron (per 100 g) for Mongolia, Cambodia and the Philippines were comparable with those proposed for the fortified CSB when intended as complementary food for children aged 12–36 months.
- Fortificant levels appeared negligible for zinc in Cambodia and Mongolia, despite a high prevalence of low serum zinc concentrations, emphasising the necessity to better define cut-offs for risk of zinc deficiency in young children.

in Asia and elsewhere. As a result, both the IOM (2003) and the WHO/FAO (2006) suggest using external estimates of within-person variation to adjust the distribution of observed intakes to usual intakes, a procedure used earlier by Jahn *et al.* (2005).

To our knowledge, this is the first report to use actual dietary intake data collected from three Asian countries – the Philippines, Mongolia and Cambodia – to establish appropriate fortificant levels of calcium, iron and zinc for the diets of infants and young children using the WHO/FAO's (2006) recommended approach. The nutrient intake data from the Philippines were collected on 2 days during the 2003 National Food Consumption Survey (Pedro *et al.* 2005a,b), whereas for Mongolia and Cambodia, data were based on single 24-h recalls; details are described elsewhere (Anderson *et al.* 2008a; Lander *et al.* 2010). As a result, we applied external variance estimates of within-person variation estimated from the 2003 Filipino national survey for calcium and iron, and from the 2002 US National Health and Nutrition Examination Survey (NHANES) III survey for zinc to calculate the distribution of usual intakes. Calcium, iron and zinc were chosen because they have been defined as problem micronutrients by WHO, based on

the large discrepancy that often exists between the contribution of these micronutrients from foods and the amount required by breastfed and non-breastfed children (WHO 2004, 2005). Our specific objectives were to: (1) assess the prevalence of inadequate and potentially excessive intakes for calcium, iron and zinc using the WHO/FAO (2006) recommended methods; and (2) establish the fortificant levels that achieve a desirably low prevalence of both inadequate and excessive intakes (i.e. 2–3%) for these micronutrients in the diets for young children in the Philippines, Mongolia and Cambodia.

Subjects and methods

Details of the methods used to collect the socio-demographic, anthropometric and biochemical data for the population groups included here have been reported previously (Pedro *et al.* 2005a,b; Lander *et al.* 2008; Anderson *et al.* 2008b). In this report, we provide selected data for the children (Table 1).

Collection of the dietary intake data

Dietary intake data from the Philippines, Mongolia and Cambodia were used to model appropriate levels

Table 1. Selected demographic, anthropometric, anaemia and micronutrient status of the Filipino, Mongolian and Cambodian target groups

	Philippines	Mongolia	Cambodia
Age range			
6–11 months	135	–	–
12–36 months	1239	179	177
Anthropometric status			
Stunted (HAZ <–2 SD) (%)	30*	16	64
Wasted (WHZ <–2 SD) (%)	5*	0	12
Underweight (WAZ <–2 SD) (%)	27*	4	46
Micronutrient intakes [†]			
Calcium mg day ^{–1}	142 (68, 278)	244 (189, 310)	200 (156, 266)
Zinc mg day ^{–1}	ND	5.1 (4.0, 6.3)	2.6 (2.1, 3.2)
Iron mg day ^{–1}	2.2 (1.2, 4.3)	4.5 (3.7, 5.4)	6.1 (4.9, 7.5)
Biochemical nutrient status			
Anaemia (%) [‡]	32 [§]	24	19
Iron-deficiency anaemia (%) [¶]	ND	16	9
Low storage iron (%) ^{**}	ND	21	4
Low serum zinc (%) ^{††}	ND	74	55

HAZ, height-for-age z-score; ND, not determined; SD, standard deviation; WAZ, weight-for-age z-score; WHZ, weight-for-height z-score. *Data are for children 0–60 months. [†]Median (interquartile range) for children aged 12–36 months. [‡]Haemoglobin <110 g L^{–1}. [§]Data are for children aged 6–60 months. [¶]Haemoglobin <110 g L^{–1} and serum ferritin <12 µg L^{–1} [in the absence of elevated C-reactive protein (CRP) indicative of acute infection]. ^{**}Serum ferritin <12 µg L^{–1}, indicative of low iron stores (in the absence of elevated CRP indicative of acute infection). ^{††}Serum zinc <9.9 µmol L^{–1} (in the absence of elevated CRP indicative of acute infection).

of fortification for the diets of young children in each respective country. Dietary data for non-breastfed children aged 6–36 months from the Philippines, collected during the 2003 National Food Consumption Survey, were based on randomly selected children from all the provinces of the country using a stratified multistage sampling procedure; details are available elsewhere (Pedro *et al.* 2005a,b). Briefly, two independent days of dietary intake data were collected: the first day was based on a 24-h recall administered by a trained interviewer in the home, whereas the second day comprised an in-home diet record in which portion sizes were estimated by a trained research assistant using household measures and dietary scales. Details of ingredients of mixed dishes, cooking methods and the amount of each mixed dish consumed by the children were also recorded. The Filipino food composition table [Food and Nutrition Research Institute (FNRI) 1997], augmented where necessary with nutrient composition values from other tables, was used to compute the energy and nutrient intakes. Nutrient composition values for zinc were not listed in the Filipino food composition table, so only calcium and iron intakes were available for this report.

The Mongolian data set used dietary intakes for children aged 12–36 months collected during a cross-sectional survey of urban and semi-urban children aged 6–36 months. Children were recruited from four districts in Ulaanbaatar, the capital city of Mongolia, and the four provincial capitals of Bulgan, Bayanhongor, Dornod and Khovd, located in the northern, southern, eastern and western parts of Mongolia, respectively, as described elsewhere (Lander *et al.* 2010). Dietary data were based on single interactive multiple-pass 24-recall interviews conducted in the children's homes by trained interviewers (Gibson & Ferguson 2008). Portion sizes were estimated using calibrated household utensils, with the exception of those for the wheat-based porridges, which were weighed. Intakes of energy and nutrients were calculated using a unique Mongolian food composition table, compiled from the analysed values for the calcium, iron, zinc and phytate concentrations of staple porridges, together with literature values (Lander *et al.* 2010).

The Cambodian data set was also based on a cross-sectional survey of mainly non-breastfed children aged 12–36 months, who were recruited from one of the poorest districts of Phnom Penh, and were stunted (i.e. length- or height-for-age z -score <-2 SD) but with no evidence of chronic disease. Dietary intakes based on single 24-h recalls were collected from the primary caregivers of the children by trained interviewers, as described for the Mongolian study (Lander *et al.* 2010). Intakes of energy and nutrients were calculated from a Cambodian food composition table, based on the analysed values and the literature (Anderson *et al.* 2008a).

Estimation of desirable fortification levels

We used three steps to estimate the desirable fortification levels from the actual dietary intake data using the WHO/FAO's (2006) recommended approach; details are outlined below.

Adjustment for usual nutrient intakes

The first step involved adjusting the distribution of observed intakes of calcium and iron for the Filipino infants (6–12 months) and toddlers (12–23 months) accounting for the day-to-day variability in intakes (within-person variation), and calculating the distribution of usual intakes. This was achieved by using the software program PC-SIDE (version 1.02, 2001, Iowa State University, Ames, IA, USA) and the associated documentation; further details are described elsewhere (Nusser *et al.* 1996; Guenther *et al.* 1997; Carriquiry 2003). PC-SIDE generated estimates of within- : between-person variance component ratios and their respective fourth moment of error values for intakes of calcium and iron for the Filipino children. The estimates of the variance ratios for the Filipino toddlers were then used to adjust the distribution of observed intakes of calcium and iron for the Mongolian and Cambodian toddlers to usual intakes using PC-SIDE. The use of external variance estimates to adjust nutrient intake distributions in this way has been reported earlier by Jahns *et al.* (2005), but the process has not been widely used. For zinc, external estimates of variance for intakes based on 24-h recalls (and some

repeats) from US children aged 12–47 months participating in the US NHANES 2002 survey (Goldman 2005) were applied to adjust the distribution of observed to usual intakes for the Mongolian and Cambodian data sets because of the absence of data on zinc intakes for the Filipino children.

Determination of the prevalence of inadequate and potentially excessive nutrient intakes

In the second step, the cut-point method was applied to estimate the prevalence of both inadequate intakes of calcium and zinc, and potentially excessive intakes of calcium, zinc and iron. The approach involved calculating the proportion of children in the target group with usual intakes below the EAR and above the UL, respectively. For calcium, the EARs and ULs set by WHO/FAO (2004) were used, whereas for zinc, the EAR set by the International Zinc Nutrition Consultative Group (IZiNCG; i.e. 2 mg day⁻¹ for a mixed or refined vegetarian diet) (Brown *et al.* 2004) and the UL (i.e. 7 mg) set by the Institute of Medicine (IOM 2001) for children aged 12–36 months were applied. The UL set by WHO/FAO (2004) was used for iron to estimate the prevalence of potentially excessive intakes.

In contrast, to estimate the prevalence of inadequate intakes for iron, the full-probability approach was used because the distribution of iron requirements for children is not symmetric about the EAR, thus violating one of the assumptions required for using the cut-point method (IOM 2003; WHO/FAO 2006). Calculations were performed in conjunction with the tabulated values published by WHO/FAO (2006) for the probability of inadequate intakes of iron for children aged 12–36 months at different ranges of usual intake (mg day⁻¹), assuming 10% bioavailability. This level of bioavailability was assumed because the children's diets were based predominantly on polished rice or refined wheat flour with relatively low-phytate content (Perlas & Gibson 2005; Anderson *et al.* 2008a; Lander *et al.* 2010). The first stage in the calculation was to determine the number of children in each target group with usual iron intakes in each of the 14 classes of a specified range of intake, as defined by WHO/FAO (2006).

Next, each number was converted to a percentage of the target group, which was then multiplied by the appropriate probability for each of the 14 classes to yield the prevalence of children (as %) who were likely to have iron intakes below their own requirements. The sum of the percentages for each target group represented the total probability of inadequate intakes of iron (as a percentage) for that group of children.

We also investigated the validity of applying the external estimates of within-person variance for adjusting the usual intake distributions for calcium and iron in order to calculate the prevalence of inadequate intakes. To accomplish this objective, we compared the prevalence of inadequate intakes of calcium and iron for the two age groups of Filipino children, based on the distribution of observed intakes adjusted to usual intakes by using the true within-person variance, as well as external estimates of within-person variance for intakes of calcium and iron, derived from data on Belgium pre-school children aged 2.5–3 years recruited using a multistage cluster sampling design (Huybrechts *et al.* 2008).

Estimation of desirable levels of fortification

In this step, the usual intake distributions for calcium and zinc for each of the target groups were repositioned so that the 2.5th percentile for each distribution and target population equalled the EAR. The amount of nutrient required to reposition the median for the target population equates to the amount of fortificant that needs to be added to the diet. We used the term 'nutrient gap' to denote the difference between the target median intake and the baseline median intake. If every person in the population were to consume an additional amount of the nutrient equal to the gap, then the population would achieve the target 2–3% prevalence of inadequate intakes. For iron, an iterative process was used to estimate the fortificant levels. Incremental amounts of iron were added to the usual intake distribution, and the prevalence of inadequate intakes of iron was recalculated using the probability approach until the amount of iron added yielded an acceptably low prevalence of inadequate intakes (i.e. 2–3%).

Estimation of the nutrient gap provides an initial guess of the amount of nutrient to add to one or more food vehicles as a fortificant. Because in a group, the intake of food vehicles is also subject to between- and within-person variability, it is also necessary to evaluate whether adding an amount equal to the gap to a specific vehicle will achieve not only a desirably low prevalence of inadequate intakes but also a low prevalence of excessive intakes in the diets of the children post-fortification. We achieved this goal by simulating the effect of fortifying the children's diets with the estimated fortificant levels for iron and calcium. In cases where the prevalence of excessive intakes was greater than 2.5%, the level of fortification was reduced, and the cut-point method was reran until an acceptable balance was reached in terms of planning for a low prevalence of both inadequate and excessive intakes.

The amount of micronutrient fortificant required to fill the nutrient gap for each target group was expressed per average serving size, based on the serving size recommendations of Lutter and Dewey (2003), which vary according to age group and per 100 g.

Results

Socio-demographic, anthropometric and micronutrient status

Table 1 summarises the selected socio-demographic, anthropometric and biochemical micronutrient status for each population group. None of the Filipino infants or toddlers was breastfeeding, whereas 19% of the Cambodian and 60% of the Mongolian toddlers were still breastfeeding. The prevalence of stunting (height-for-age z -scores <-2 SD) was highest for the Cambodian toddlers (64%), followed by the Filipino children less than 5 years of age (30%); only 16% of toddlers from Mongolia were stunted. The prevalence of wasting was much lower, but followed the same trend as stunting: more Cambodian toddlers (12%) were wasted compared with 5% of children less than 5 years of age in the Philippines; none of the Mongolian toddlers were wasted. Almost half of the Cambodian toddlers were also underweight com-

pared with 27% of children less than 5 years in the Philippines; only 4% of the Mongolian toddlers were underweight.

Median intakes of calcium, iron and zinc for the toddlers aged 12–36 months, adjusted to usual intakes by removing the day-to-day variability in intakes (within-person variation) using PC-SIDE, are also shown in Table 1. Median usual calcium intakes were lower for the Filipino toddlers compared with those from Mongolia and Cambodia. Likewise, the median usual iron intakes for the Filipino toddlers were markedly lower than those for the toddlers in Cambodia, and to a lesser extent, Mongolia. In contrast, the median usual zinc intake for the Cambodian toddlers was lower than those from Mongolia. The overall prevalence of anaemia for the Mongolian and Cambodian toddlers was comparable (~20%), although the prevalence of both iron-deficiency anaemia and low iron stores was seemingly lower for the toddlers in Cambodia compared with Mongolia, based on low haemoglobin and ferritin concentrations [in the absence of elevated C-reactive protein (CRP)] (Table 1). The prevalence of low serum zinc concentrations was very high in both the Mongolian and the Cambodian toddlers, and greater than the prevalence of anaemia among the toddlers in these two countries.

Prevalence of inadequate and potentially excessive intakes

Table 2 compares the within- to between-person variance component ratios and the associated fourth

Table 2. Variance estimates of calcium, iron and zinc in young children (12–36 months) used to statistically adjust observed intakes to usual intake distributions using PC-SIDE

	Calcium	Iron	Zinc
Philippines, 2003	0.73 (6.7)	0.68 (4.7)	ND
Belgium, 2008*	0.47	0.47	
United States, NHANES II [†]			0.67

ND, not determined; NHANES, National Health And Nutrition Examination Survey. Values expressed as proportion of total variance attributed to within-person variation (fourth moment of error).

*From Huybrechts *et al.* (2008). [†]From Goldman (2005).

Table 3. Prevalence* of inadequate intakes of calcium and iron in Filipino children using internal and external variance estimates

	Calcium		Iron	
	Internal adjustment	External adjustment	Internal adjustment	External adjustment
6–12 months	30 (2.7)	49 (4.8)	80 (3.4)	81 (3.5)
12–36 months	89 (1.3)	92 (1.5)	83 (1.1)	83 (1.1)

*Values expressed as a percentage (standard error).

Table 4. Prevalence* of inadequate and excessive intakes of calcium, iron and zinc

	Calcium		Iron		Zinc	
	Inadequate	Excessive	Inadequate	Excessive	Inadequate	Excessive
Philippines						
6–11 months	30	No UL	80	<1 [‡]	ND	ND
12–36 months	89	<1 [†]	83	<1 [‡]	ND	ND
Mongolia						
12–36 months	98	<1 [†]	70	<1 [‡]	<1	11 [§]
Cambodia						
12–36 months	95	<1 [†]	41	<1 [‡]	20	<1 [§]

ND, No data collected on zinc intakes. *Values expressed as a percentage. [†]UL for calcium for children 12–36 months is 2500 mg (WHO/FAO 2006). [‡]UL for iron for infants 6–11 months and children 12–36 months is 40 mg (WHO/FAO 2006). [§]UL for zinc for children 12–36 months is 7 mg (IOM 2001).

moment of error values generated for the calcium and iron intakes for the Filipino toddlers and the corresponding values generated from data on Belgium toddlers. The prevalence of inadequate intakes of calcium and iron among the Filipino toddlers based on their actual variance estimates vs. the external estimates (Table 2) are presented in Table 3. There was almost no difference in the prevalence of inadequate intakes of iron in the two age groups, regardless of the variance estimates applied, whereas for the prevalence of inadequate intakes of calcium, the magnitude of the difference was dependent on the age group. The use of the Belgian external variance estimates overestimated the prevalence of inadequate calcium intakes in Filipino infants, but yielded comparable prevalence estimates for the Filipino toddlers.

Table 4 presents the prevalence of inadequate and potentially excessive intakes of calcium, iron and zinc based on the corresponding EARs and ULs, respectively. Toddlers from all three countries had a high prevalence of inadequate intakes of calcium (89–98%), whereas the prevalence estimate was much

lower (30%) for the Filipino infants. There was also a high prevalence of inadequate intakes of iron among the Mongolian and Filipino toddlers, as well as Filipino infants, although the prevalence for the Cambodian toddlers was lower (41%). By contrast, the prevalence of inadequate intakes of zinc for the Mongolian toddlers was less than 1%, although 20% for Cambodian toddlers. Less than 1% of the children from each country had intakes of calcium and iron in excess of the UL, whereas for zinc, the prevalence of intakes above the UL was <1% in Cambodia but 11% in Mongolia.

Estimation of desirable levels of fortification

Table 5 presents the level of calcium and iron fortificants required to plan for both a low prevalence of inadequate and excessive intakes in each target population group in the three Asian countries. Calcium fortificant levels necessary to ensure a low prevalence of inadequate (2–3%) and excessive (<1%) intakes ranged from 313 to 389 mg of calcium per daily ration

Table 5. Level of fortification required per daily ration and per 100 g of fortified complementary food

	Serving size* (g)	Per daily ration			Per 100 g dry weight		
		Iron [†] (mg)	Zinc [‡]	Calcium [§] (mg)	Iron [†] (mg)	Zinc [‡]	Calcium [§] (mg)
Philippines							
6–12 months	40	9.1	ND	313	22.8	ND	783
12–36 months	60	9.8	ND	389	16.3	ND	648
Mongolia							
12–36 months	60	8.0	0 mg	323	13.3	0 mg	538
Cambodia							
12–36 months	60	6.5	0.6 mg	318	10.8	1 mg	530

ND, not determined. *Serving sizes according to Lutter & Dewey (2003). [†]Derived using the full-probability approach assuming a 10% bioavailability for iron (IOM 2003). [‡]Derived using the estimated average requirement (EAR) cut-point method using International Zinc Nutrition Consultative Group EAR for Zn based on mixed or refined vegetarian diet (2 mg day⁻¹) (Brown *et al.* 2004). [§]Derived using the EAR cut-point method using WHO EAR for calcium (7–12 months: 330 mg day⁻¹; 1–3 years: 417 mg day⁻¹) (WHO/FAO 2006).

for the Filipino infants and toddlers, respectively. Assuming an average serving size of cereal porridge of 60 g dry weight for children aged 6–23 months, as recommended by Lutter & Dewey (2003), this equated to a fortification level of about 530 mg calcium per 100 g dry weight for cereal-based porridges for both the Mongolian and the Cambodian toddlers, and ~648–783 mg calcium per 100 g dry weight for the Filipino infants and toddlers. Corresponding fortificant levels for iron in cereal blends, again calculated to ensure a low prevalence of both inadequate and excessive intakes, assuming moderate bioavailability, ranged from 10.8 mg per 100 g dry weight for Cambodian toddlers to 22.8 mg per 100 g dry weight for Filipino infants. No fortificant levels were calculated for zinc in Mongolia because of the seemingly very low prevalence of inadequate zinc intakes, and in Cambodia, only an additional 0.6 mg zinc per daily ration was required to ensure a low prevalence (2–3%) of inadequate zinc intakes.

Discussion

Most of the target population groups of Asian children studied here had a high prevalence of inadequate intakes of calcium and iron, justifying fortifying their diets with these two micronutrients. In contrast, because of the seemingly much lower prevalence of inadequate zinc intakes among the toddlers, only a small amount of zinc fortificant appeared warranted in the Cambodian diets and none in Mongolia.

This finding was not in accordance with their risk of zinc deficiency based on the prevalence of low serum zinc concentrations and highlights the need for better defined cut-offs for risk of suboptimal zinc status in young children.

Prevalence of inadequate intakes of calcium, iron and zinc, and fortificant levels required

In view of the absence of any replicate days of dietary intake data for the toddlers from Cambodia and Mongolia, we applied external estimates of within-person variance calculated from 2 days of dietary intake data collected from a nationally representative sample of non-breastfed children of similar age from the Philippines, as recommended by WHO/FAO (2006). It is of interest that the prevalence of inadequate intakes of iron and calcium for the non-breastfed Filipino toddlers, based on both within-person variance estimates generated from the Filipino dietary data and external estimates from the literature, were reasonably comparable (Table 4), as reported earlier by Jahns *et al.* (2005). However, for the non-breastfed Filipino infants aged 6–12 months, the level of agreement for the prevalence of inadequate intakes of calcium was lower, perhaps because the external within-person variance for calcium was based on data from Belgium pre-school children aged 2.5–3 years and not on infants. Based on these findings, the use of external estimates of within-person variation to adjust the distribution of

observed intakes of the toddlers in the Mongolian and Cambodian data sets to usual intakes, at least for calcium and iron, appeared justified.

Of the three micronutrients, the prevalence of inadequate intakes for most population groups was highest for calcium, followed closely by iron. However, our prevalence estimates for calcium were slightly overestimated because we excluded the contribution of calcium from breast milk, even though some of the toddlers were still breastfeeding; the estimated contribution of calcium from breast milk in toddlers aged 12–23 months is ~100 mg day⁻¹ (Abrams & Atkinson 2003). Other investigators have reported large deficits in calcium intakes among breastfed Asian infants and toddlers (Kimmons *et al.* 2005), attributed to diets based predominately on cereals, with a low content of calcium-rich dairy products. Very few (<1%) of the Asian children of this study had calcium intakes above the UL (WHO/FAO 2006), irrespective of setting.

Our estimates for the levels of calcium fortification required in the daily diets to ensure a desirably low prevalence of both inadequate (2.5%) and excessive (<1%) intakes of calcium were lowest for the infants and highest for the toddlers from the Philippines, whether expressed in terms of intake of an average daily ration (in grammes) or per 100 g food vehicle as recommended by WHO/FAO (2006) (Table 5). When expressed per 100 g food vehicle, our calculated calcium fortificant levels were very comparable with the recent level (i.e. 734 mg Ca per 100 g) recommended for the fortified blended food – corn–soy blend (CSB) intended for use as a complementary food (Fleige *et al.* 2010), but higher than levels proposed earlier by Lutter & Dewey (2003) (i.e. 200–400 mg Ca per 100 g). The latter was based on recommendations by Abrams & Atkinson (2003) who did not use the WHO/FAO 2006 approach applied here to set the fortificant levels.

Interestingly, the calcium fortificant levels (per 100 g dry flour) of 32 manufactured fortified cereal-based infant foods sold in Asia and analysed earlier in our laboratory (Gibbs *et al.* 2011) were all below our estimates for achieving a desirably low level of inadequate intakes of calcium for our targeted population groups, although their analysed calcium fortificant

levels (per 100 g dry flour) were comparable with those proposed by Lutter & Dewey (2003).

Like calcium, the prevalence of inadequate intakes of iron was high for the toddlers from the Philippines and Mongolia, as well as the Filipino infants. However, estimates for the Cambodian toddlers were much lower (41%), attributed to the consumption of iron-fortified breast milk substitutes by non-breastfeeding toddlers and rice porridge (borbor) mixed with pork blood (Anderson *et al.* 2008a). Consequently, fortificant estimates for iron were lowest for the Cambodian toddlers and highest for the infants and toddlers from the Philippines (Table 5). None of the children had iron intakes from their usual diets that exceeded the UL (40 mg) (Ottens *et al.* 2006). Our estimates for iron fortification (per 100 g food vehicle) were also within the ranges proposed for the fortified blended food – CSB (i.e. 17.1 mg per 100 g) for use as a complementary food (Fleige *et al.* 2010), as well as those by Lutter & Dewey (2003). Furthermore, depending on the country, when expressed as a daily ration (Table 5), the iron fortificant levels proposed here were either similar or slightly lower than the iron content of the micronutrient powders – Sprinkles (i.e. 10 mg Fe per daily sachet) – recommended by the Home Fortification Technical Advisory Group (HFTAG 2012).

Fortification of cereal-based complementary foods with bioavailable iron fortificants at these levels have reduced anaemia (López De Romaña 2000; Rivera *et al.* 2004; Faber *et al.* 2005; Lutter *et al.* 2008; Rim *et al.* 2008), improved iron status (Faber *et al.* 2005) and in some cases, motor development (Faber *et al.* 2005). These cereal-based fortified foods for young children were also co-fortified with ascorbic acid at molar ratios of $\geq 3:1$ to overcome any inhibitory effect of phytate on non-haem iron absorption (Davidsson *et al.* 2009). It is noteworthy that when we simulated the impact of consuming three manufactured iron-fortified cereal-based infant foods sold in Asia, on the prevalence of inadequate intakes of iron in the targeted populations, the iron fortificant levels for all three products were too low to ensure a low prevalence of inadequate dietary iron intakes. An exception was the Cambodian toddlers aged 12–36 months, in whom the prevalence estimate of

inadequate intakes of iron was only 2.4% for one of the products.

The prevalence of inadequate intakes of zinc, in contrast to both calcium and iron, was less than 1% for the toddlers in Mongolia, although higher in Cambodia (20%). Hence, these findings suggest that zinc fortification is only warranted in Cambodia. However, the low prevalence of inadequate intakes of zinc observed here was unexpected given that more than 50% of both the Mongolian toddlers and the Cambodian toddlers (Lander *et al.* 2008; Anderson *et al.* 2008b) had serum zinc concentrations at levels said to be indicative of risk of zinc deficiency (Hess *et al.* 2007). Several other studies have also reported a marked lack of concordance between the predicted risk of zinc deficiency based on the prevalence of inadequate zinc intakes and low serum zinc concentrations (Morgan *et al.* 2010; Gibson *et al.* 2011), and this discrepancy appears to be greater for children than for adults (Hotz 2007). Several factors may account for these findings, including uncertainties in the dietary intake data per se, the cut-offs used to define both the EAR for zinc (Hotz 2007) and low serum zinc concentrations (Hess *et al.* 2007), and the wide array of confounding factors known to influence serum zinc concentrations (Hess *et al.* 2007). In this study, we used the EAR for the toddlers set by IZiNCG that corresponded to a mixed or refined vegetarian diet (Brown *et al.* 2004), after taking into account the low analysed phytate : zinc molar ratios of the Cambodian and Mongolian children's diets (Anderson *et al.* 2008a; Lander *et al.* 2010). However, recent research indicates that in adults, the magnitude of the inhibitory effect of dietary phytate on zinc absorption is probably much greater than previously recognised, although whether this is also the case for young children is less certain (Hambidge *et al.* 2008). Tropical enteropathy may be an additional factor exacerbating risk of zinc deficiency among the Mongolian and Cambodian toddlers studied here (Manary *et al.* 2010), which was not taken into account when the EAR was set by IZiNCG for young children living in low-income countries. Clearly, more data are required to establish EARs for zinc among infants and young children in a variety of settings (Hotz 2007). It is noteworthy that 11% of the young children

in Mongolia had usual dietary zinc intakes in excess of the UL (IOM 2001). This trend has been reported by others in the diets of US pre-school children (Arsenault & Brown 2003) and has prompted concern about the appropriateness of the current UL for zinc for young children (Arsenault & Brown 2003; Zlotkin 2006; Hess & Brown 2009).

Limitations

We recognise that this study is limited by the absence of dietary data based on nationally representative samples for the Mongolian and the Cambodian children studied here, unlike the national sample for the Filipino children. Nevertheless, the prevalence of stunting, anaemia, use of vitamin A supplements and breastfeeding practices in these two targeted groups were comparable with those reported in the national surveys in Mongolia [Nutrition Research Center/United Nations Children's Fund (NRC/UNICEF) 2002] and Cambodia [National Institute of Statistics (NIS) 2001]. Uncertainties also exist for the fortificant levels generated because the calculations were based on several assumptions. We excluded the micronutrient contribution from breast milk in our calculations because none of the Filipino infants and not all the toddlers were breastfed, and breast milk provides only a small contribution towards the total requirements for iron and zinc for toddlers (Lutter & Dewey 2006). Excluding the contribution of calcium from breast milk, however, would result in an overestimate for the prevalence of inadequate calcium intakes, but would not pose any risk for excessive intakes after fortification because the UL for calcium is so high (i.e. 2.5 g) (IOM 1997; WHO/FAO 2006). In addition, we recognise that our prevalence estimates for inadequate intakes of calcium, zinc and iron are all limited by uncertainties in the nutrient intake data and in the EARs set for infants and toddlers, as well as by our use of the EAR cut-point method to generate the estimates for calcium and zinc. For example, most of the dietary data were collected from the caregivers by 24-h recalls, although the portion sizes recalled as consumed were weighed to enhance their accuracy, and the nutrient values for iron, zinc, calcium and phytate content of the porridges in Mongolia (i.e.

semolina) and Cambodia (i.e. rice) were based on chemical analysis in our laboratory (Anderson *et al.* 2008a; Lander *et al.* 2010). Furthermore, the reliability of the EAR cut-point method for estimating the prevalence of inadequate intakes is reduced when levels of inadequacy are zero or 100% (IOM 2003). Finally, application of the WHO/FAO's (2006) guidelines for fortification also assumes that the diets of the children post-fortification remain unchanged, which may not be the case, especially if the fortified food is expensive, when it may be diluted, or perhaps displace the consumption of indigenous nutrient-dense foods.

Conclusions

Among these Asian children, we observed a very high prevalence of inadequate intakes for calcium and iron, but not for zinc, despite the high prevalence of low serum zinc concentrations. This lack of concordance suggests the need for better defined cut-offs for risk of zinc deficiency in children based on the prevalence of inadequate intakes of dietary zinc and/or low serum zinc concentrations. Our estimate for calcium (but not iron) fortificant levels (expressed as mg per 100 g or per daily ration size) to achieve a desirably low prevalence of inadequacy (i.e. <2–3%) exceeded that proposed earlier by Lutter & Dewey (2003). However, both our calcium and iron fortificant levels (per 100 g) were comparable with those proposed for the fortified blended food – CSB – when intended as complementary food for children aged 12–36 months.

Acknowledgements

We wish to thank Rebecca Lander, Victoria Anderson and Regina Pedro for their role in collecting the dietary intake data from Cambodia, Mongolia and the 2003 National Nutrition Survey in the Philippines, respectively.

Source of funding

Michelle M. Gibbs was supported by a Postgraduate Publishing Bursary awarded by the University of Otago Research Committee.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Contribution

RSG and MMG designed the research project and developed the overall research plan. MMG conducted the study, with guidance in the statistical analyses and interpretation from ALC and RSG. MVC provided the dietary data from the 2003 National Nutrition Survey in the Philippines. MMG, RSG and ALC wrote the paper; and RSG had primary responsibility for final content. All authors have read and approved the final manuscript.

References

- Abrams S.A. & Atkinson S.A. (2003) Calcium, magnesium, phosphorous and vitamin D fortification of complementary foods. *Journal of Nutrition* **133**, S2994–S2999.
- Anderson V.P., Cornwall J., Jack S. & Gibson R.S. (2008a) Intakes from non-breastmilk foods for stunted toddlers living in poor urban villages of Phnom Penh, Cambodia, are inadequate. *Maternal and Child Nutrition* **4**, 146–159.
- Anderson V.P., Jack S., Monchy D., Hem N., Hok P., Bailey K.B. *et al.* (2008b) Co-existing micronutrient deficiencies among stunted Cambodian infants and toddlers. *Asia Pacific Journal of Clinical Nutrition* **17**, 146–159.
- Arsenault J.E. & Brown K. (2003) Zinc intakes of US preschool children exceeds new dietary reference intakes. *American Journal of Clinical Nutrition* **78**, 1011–1017.
- Brown K.H., Rivera J.A., Bhutta Z.A., Gibson R.S., King J.C., Lönnerdal B. *et al.* (2004) International Zinc Nutrition Consultative Group (IZiNCG) Technical Document # 1. Assessment of the risk of zinc deficiency in populations and options for its control. *Food and Nutrition Bulletin* **25**, S94–S203.
- Carriquiry A. (2003) Estimation of the usual intake distributions of nutrients and foods. *Journal of Nutrition* **133**, S601–S608.
- Davidsson L., Sarker S.A., Jamil K.A., Sultana S. & Hurrell R. (2009) Regular consumption of a complementary food fortified with ascorbic acid and ferrous fumarate or ferric pyrophosphate is as useful as ferrous sulfate in maintaining hemoglobin concentrations >105 g/L in young Bangladeshi children. *American Journal of Clinical Nutrition* **89**, 1815–1820.

- Dewey K.G. & Adu-Afarwuah S. (2008) Systematic review of the efficacy and effectiveness of complementary feeding interventions in developing countries. *Maternal and Child Nutrition* **4**, 24–85.
- Faber M., Kvalsvig J.D., Lombard C.J. & Benade A.J.S. (2005) Effect of a fortified maize-meal porridge on anemia, micronutrient status, and motor development of infants. *American Journal of Clinical Nutrition* **82**, 1032–1039.
- Ferguson E.L. & Darmon N. (2007) Traditional foods vs. manufactured baby foods. *Nestle Nutrition Workshop Series: Pediatric Program* **60**, 43–61.
- Fleige L.E., Sahyoun N.R. & Murphy S.P. (2010) A new simulation model estimates micronutrient levels to include in fortified blended foods used in food aid programs. *Journal of Nutrition* **140**, 355–365.
- Food and Nutrition Research Institute (FNRI) (1997) *The Philippine Food Composition Tables 1997*. Metro Manila, Philippines.
- Fox M.K., Reidy K., Novak T. & Ziegler P. (2006) Sources of energy and nutrients in the diets of infants and toddlers. *Journal of the American Dietetic Association* **106**, S28–S42.
- Gibbs M., Bailey K.B., Lander R., Fahmida U., Perlas L., Hess S. *et al.* (2011) The adequacy of micronutrient concentrations in manufactured complementary foods from low-income countries. *Journal of Food Composition and Analysis* **24**, 418–426.
- Gibson R.S. & Ferguson E.L. (2008) *An interactive 24-hour recall for assessing the adequacy of iron and zinc intakes in developing countries*. Harvest Plus Technical Monograph 8. International Food Policy Research Institute (IFPRI) and International Center for Tropical Agriculture (CIAT). Washington, DC and Cali.
- 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**, 764–770.
- Gibson R.S., Bailey K.B., Parnell W.R., Wilson N. & Ferguson E.L. (2011) Higher risk of zinc deficiency in New Zealand Pacific school children compared with their Maori and European counterparts: a New Zealand national survey. *British Journal of Nutrition* **105**, 436–446.
- Goldman J. (2005) Within-individual variance estimates for nutrients from What We Eat in America, NHANES 2002. U.S. Department of Agriculture, Agricultural Research Service.
- Guenther P.M., Kott P.S. & Carriquiry A.L. (1997) Development of an approach for estimating usual nutrient intake distributions at the population level. *Journal of Nutrition* **127**, 1106–1112.
- Hambidge K.M., Miller L.V., Westcott J.E. & Krebs N.F. (2008) Dietary reference intakes for zinc may require adjustment for phytate intake based upon model predictions. *Journal of Nutrition* **138**, 2363–2366.
- Hess S.Y. & Brown K.H. (2009) Impact of zinc fortification on zinc nutrition. *Food and Nutrition Bulletin* **30**, S79–S105.
- Hess S.Y., Pearson J.M., King J.C. & Brown K.H. (2007) Use of serum zinc concentration as an indicator of population zinc status. *Food and Nutrition Bulletin* **28**, S403–S429.
- Home Fortification Technical Advisory Group (HFTAG) (2012) *Programmatic guidance brief on use of micronutrient powders (MNP) for home fortification*. Prepared by World Food Programme, UNICEF, Micronutrient Initiative, Sprinkles Global Initiative, Helen Keller, Sight and Life, Centers for Disease Control and Prevention, UC Davis, Global Alliance for Improved Nutrition.
- Hotz C. (2007) Dietary indicators for assessing the adequacy of population zinc intakes. *Food and Nutrition Bulletin* **28**, S430–S448.
- Huffman S.L., Onian'g R. & Quinn V. (2000) Improving young child feeding with processed complementary cereals and behavioural change in urban Kenya. *Food and Nutrition Bulletin* **21**, 75–81.
- Huybrechts I., De Bacquer D., Cox B., Temme E., Van Oyen H., De Backer G. *et al.* (2008) Variation in energy and nutrient intakes among pre-school children: implications for study design. *European Journal of Public Health* **18**, 509–516.
- Institute of Medicine (IOM) (1997) *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. National Academy Press: Washington, DC.
- Institute of Medicine (IOM) (2001) *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. National Academy Press: Washington, DC.
- Institute of Medicine (IOM) (2003) *Dietary Reference Intakes: Applications in Dietary Planning*. National Academy Press: Washington, DC.
- Jahns L., Arab L., Carriquiry A. & Popkin B.M. (2005) The use of external within-person variance estimates to adjust nutrient intake distributions over time and across populations. *Public Health Nutrition* **8**, 69–76.
- Kimmons J.E., Dewey K.G., Haque E., Chakraborty J., Osendarp S. & Brown K. (2005) Low nutrient intakes among infants in rural Bangladesh are attributable to low intake and micronutrient density of complementary foods. *Journal of Nutrition* **135**, 444–451.
- Lander R.D., Enkhjargal T., Batjargal J., Bolormaa N., Enkhmyagmar D., Tserendolgor U. *et al.* (2010) Poor dietary quality of complementary foods is associated with multi-micronutrient deficiencies during early childhood in Mongolia. *Public Health Nutrition* **13**, 1304–1313.

- Lander R.L., Enkhjargal T., Batjargal J., Bailey K.B., Diouf S., Green T.J. *et al.* (2008) Multiple micronutrient deficiencies persist during early childhood in Mongolia. *Asia Pacific Journal of Clinical Nutrition* **17**, 429–440.
- López De Romaña D. (2000) Experiences with the complementary feeding in the FONCODES project. *Food and Nutrition Bulletin* **21**, 43–48.
- Lutter C.K. (2000) Processed complementary foods: summary of nutritional characteristics, methods of production and distribution, and costs. *Food and Nutrition Bulletin* **21**, 95–100.
- Lutter C.K. & Dewey K.G. (2003) Proposed nutrient composition for fortified complementary foods. *Journal of Nutrition* **133**, S3011–S3020.
- Lutter C.K. & Dewey K.G. (2006) Proposed nutritional composition for fortified complementary foods. *Food and Nutrition Bulletin* **27**, 316–326.
- Lutter C.K., Rodriguez A., Fuenmayor G., Avila L., Sempertegui F. & Escobar J. (2008) Growth and micronutrient status in children receiving a fortified complementary food. *Journal of Nutrition* **138**, 379–388.
- Manary M.J., Abrams S.A., Griffin I.J., Quimper M.M., Shulman R.J., Hamzo M.G. *et al.* (2010) Perturbed zinc homeostasis in rural 3–5-y-old Malawian children is associated with abnormalities in intestinal permeability attributed to tropical enteropathy. *Pediatric Research* **67**, 671–675.
- Martorell R., Khan L.K. & Schroeder D.G. (1994) Reversibility of stunting: epidemiological findings in children from developing countries. *European Journal of Clinical Nutrition* **48**, S45–S57.
- Morgan E.J., Heath A.-L.M., Szymlek-Gay E.A., Gibson R.S., Gray A.R., Bailey K.B. *et al.* (2010) Red-meat and zinc-fortified milk intervention increase dietary zinc intakes but do not improve biochemical zinc status in New Zealand toddlers. *Journal of Nutrition* **140**, 2221–2226.
- National Institute of Statistics (NIS) (2001) Directorate General for Health (Cambodia) and ORC Macro, Cambodia, Demographic and Health Survey 2000. Phnom Penh, Cambodia and Calverton, MD, USA: National Institute of Statistics, Directorate General for Health and ORC Macro.
- Nutrition Research Center/United Nations Children's Fund (NRC/UNICEF) (2002) *Nutrition Status of Populations of Mongolia 2000–2nd National Nutrition Survey Report*. Ulaanbaatar, Mongolia, United Nations Children's Fund.
- Nusser S., Carriquiry A., Dodd K. & Fuller W. (1996) A semi-parametric transformation approach to estimating usual daily intake distributions. *Journal of the American Statistical Association* **91**, 1440–1449.
- Otten J.J., Pizi Hellwig J. & Meyers L.D. (eds) (2006) *Dietary Reference Intakes. The Essential Guide to Nutrient Requirements*. Institute of Medicine. National Academies Press: Washington, DC.
- Pedro M.R.A., Cerdeña C.M., Constantino M.A.S., Patalen M.L.P., Palafox E.F., Delos Reyes C.M. *et al.* (2005a) *Sixth National Nutrition Survey: Philippines, 2003. National Food Consumption Survey: Household Level*. Food and Nutrition Research Institute–Department of Science and Technology, Manila.
- Pedro M.R.A., Cerdeña C.M., Patalen M.L.P., Nones C.A., Vargas M.B., Laña R.D. *et al.* (2005b) *Sixth National Nutrition Survey: Philippines, 2003. Update on the Nutritional Status of Filipinos*. Food and Nutrition Research Institute–Department of Science and Technology, Manila.
- Perlas L.A. & Gibson R.S. (2005) Household dietary strategies to enhance the content and bioavailability of iron, zinc and calcium of selected rice-and maize-based Philippine complementary foods. *Maternal and Child Nutrition* **1**, 263–273.
- Rim H., Kim S., Sim B., Gang H., Kim H. & Kim Y. (2008) Effect of iron fortification of nursery complementary food on iron status of infants in the DPR Korea. *Asia Pacific Journal of Clinical Nutrition* **17**, 264–269.
- Rivera J.A., Sotres-Alvarez D., Habicht J.P., Shamah T. & Villalpando S. (2004) Impact of the Mexican program for education, health, and nutrition (Progresá) on rates of growth and anemia in infants and young children: a randomized effectiveness study. *Journal of the American Medical Association* **291**, 2563–2570.
- Victora C.G., Adair L., Fall C., Hallal P.C., Martorell R., Richter L. *et al.* (2008) Maternal and child undernutrition: consequences for adult health and human capital. *Lancet* **371**, 340–357.
- World Health Organization (WHO) (2004) *Guiding Principles for Complementary Feeding of the Breastfed Child*. World Health Organization: Geneva.
- World Health Organization (WHO) (2005) *Guiding Principles for Feeding Non-breast-fed Children Aged 6–24 Months of Age*. World Health Organization: Geneva.
- World Health Organization/Food and Agriculture Organization (WHO/FAO) (2004) *Vitamin and Mineral Requirements in Human Nutrition*, 2nd edn, World Health Organization: Geneva.
- World Health Organization/Food and Agriculture Organization (WHO/FAO) (2006) *Guidelines on Food Fortification with Micronutrients*. World Health Organization and Food and Agriculture Organization of the United Nations: Geneva.
- World Health Organization/United Nations Children's Fund (WHO/UNICEF) (1998) *Complementary Feeding*

- of Young Children in Developing Countries: A Review of Current Scientific Knowledge*. World Health Organization: Geneva.
- Ziegler E.E., Nelson S.E. & Jeter M. (2009) Iron status of breastfed infants is improved equally by medicinal iron and iron-fortified cereal. *American Journal of Clinical Nutrition* **90**, 76–87.
- Zlotkin S.H. (2006) A critical assessment of the upper intake levels for infants and children. *Journal of Nutrition* **136**, 502S–506S.