Realistic food-based approaches alone may not ensure dietary adequacy for women and young children in South-east Asia

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Running head: Food-based recommendations for southeast Asian women and children

Abstract

Objectives Micronutrient deficiencies, in southeast Asia (SE Asia), remain a public health challenge. We evaluated whether promoting the consumption of locally available nutritious foods, which is a low-risk micronutrient intervention, alone can ensure dietary adequacy, for women of reproductive age and 6 - 23 m old children. *Methods* Representative dietary data from Cambodia, Indonesia, Lao PDR, Thailand and Vietnam were analysed using linear programming analysis to identify nutrients that are likely low in personal food environments (problem nutrients), and to formulate food-based recommendations (FBRs) for three to six target populations per country. *Results* The number of problem nutrients ranged from zero for 12 – 23 m olds in Indonesia, Thailand and Vietnam to six for pregnant women in Cambodia. The FBRs selected for each target population, if adopted, would ensure a low percentage of the population was at risk of inadequate intakes for five to 10 micronutrients, depending on the country and target population. Of the 11 micronutrients modelled, requirements for iron, calcium and folate were most difficult to meet (≥10 of the 24 target populations), using FBRs alone. The number of individual FBRs selected per set, for each target population, ranged from three to eight; and often included meat, fish or eggs, liver/organ meats, vegetables and fruits. *Conclusions* Intervention strategies need to increase access to nutritious foods, including products fortified with micronutrients, in SE Asia, when aiming to ensure dietary adequacy for most individuals in the population.

Key Words: SE Asia; women; children; linear programming analyses; food-based recommendations

Significance: Promoting food-based recommendations (FBRs) is a low risk strategy to improve the micronutrient status of south-east Asian women of reproductive age and young children. It is not known, however, whether FBRs alone can be effective. Modelling results from this study suggest that, if adopted, FBRs will ensure a low percentage of these populations are at risk of inadequate intakes for between four and nine of 11 micronutrients, depending on the target population. Interventions, however, will also need to increase access to healthy food sources of micronutrients, especially food sources of calcium, iron, zinc, folate and riboflavin.

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Introduction

Chronic malnutrition remains a major public health challenge worldwide, particularly in low- and middle-income countries. In South-East Asia (SE Asia), there are marked inter-country differences in the prevalence of stunted linear growth among children under 5-years of age, ranging from less than 20% in Thailand and Malaysia to over 40% in Lao People's Democratic Republic (PDR) and Timor-Leste (World Health Organization, 2017). Micronutrient deficiencies likely contribute to stunted linear growth in SE Asia.

Globally, deficiencies of vitamin A, iron, zinc, iodine and folate are common among women of reproductive age and young children, and they often occur concurrently (Ramakrishnan, 2002). Children with micronutrient deficiencies are at risk of increased morbidity and reduced developmental potential, and women with micronutrient deficiencies are at risk of adverse birth outcomes, including low birth-weight and increased perinatal mortality (Black et al., 2013). Poor micronutrient status among lactating women may also compromise the micronutrient status of her breastfed child, because low maternal status of B-vitamins, vitamin A and iodine affects breast milk content (Allen, 2005). The prevention of micronutrient deficiencies in women of reproductive age and in young children is crucial for lifelong health benefits, the development of human capacity and economic development (Hoddinott, Alderman, Behrman, Haddad, & Horton, 2013).

Strategies employed to increase the micronutrient intakes of women and young children include fortification of staple foods, supplementation, and dietary diversification through the promotion of culturally appropriate food-based recommendations (FBRs). Promoting the consumption of locally available nutritious foods is considered the best long-term strategy for improving the nutritional status of populations because they simultaneously combat multiple micronutrient deficiencies and carry a low risk of adverse outcomes from excessive nutrient intakes (WHO, 1998). However, questions remain about whether, in resource-constrained countries, FBRs alone, if successfully adopted, can fill nutrient gaps in local diets and ensure dietary adequacy, especially for women of reproductive age and young children. Perhaps, in certain situations, supplementation, fortification and/or increasing the accessibility of nutrient dense foods must also be considered to ensure dietary adequacy (Allen, 2012).

To help answer these questions, an approach based on linear programming (LP) analysis, which simultaneously takes into account multiple factors, has been developed (Ferguson et al., 2006). This approach formulates and tests locally appropriate FBRs. In addition, it identifies nutrients that are likely to remain low in diets based only on local foods (i.e., problem nutrients). LP has been used to identify problem nutrients and formulate FBRs, for young children and women of reproductive age, in geographically limited areas of Asian and African countries (Arimond, Vitta, Martin-Prével, Moursi, & Dewey, 2017)(Raymond, Kassim, Rose, & Agaba, 2017)(Fahmida, Santika, Kolopaking, & Ferguson, 2014)(Hlaing et al., 2016)(Hlaing et al., 2016) (Hlaing et al., 2016)(Ferguson, Chege, Kimiywe, Wiesmann, & Hotz, 2015)(Santika, Fahmida, & Ferguson, 2009). This study will be the first to make inter-country comparisons, using nationally representative datasets for women of reproductive age and young children.

This study summarises key results from one work package within the **S**ustainable **M**icronutrient **I**nterventions to Contro**L** Deficiencies and **I**mprove **N**utritional status and **G**eneral Health in Asia project (SMILING). SMILING is a collaboration of research institutions and implementation agencies in five SE Asian countries (Cambodia, Indonesia, Lao PDR, Thailand and Vietnam) with European partners to explore strategies to alleviate micronutrient malnutrition in SE Asia (Berger et al., 2013). In this paper, we present findings from across all five countries. Specific objectives were to identify country-specific problem nutrients and to compare FBRs formulated for women of reproductive age and young children in each of these countries.

Methods

Study design and sampling

We sourced dietary data sets in each of the five SE Asian countries – Cambodia, Indonesia, Lao PDR, Thailand and Vietnam. The inclusion criteria for these data sets were: (1) data were collected from at least three of the following seven target populations: 6 - 8 m olds, 9 - 11 m olds, 12 - 23 m olds, adolescent girls, pregnant women, lactating women or non-pregnant and non-lactating women; (2) each sample was representative at a national (preferred), regional or local level; and (3) quantitative dietary data were collected. In Thailand, Indonesia and Vietnam, we sourced dietary data from national surveys, namely the 2003-2005 National Food Consumption survey of Thailand, the 2010 National Basic Health Research Survey (Riskesdas) of Indonesia and the 2009-2010 General Nutrition Survey (GNS) of Vietnam. In Thailand and Indonesia, we analysed only children. In Cambodia, we used randomly selected subsets of dietary data from the 2011 national survey for 12 - 23 m old children, adolescent girls, pregnant and lactating women; and locally representative survey data for 6 - 8 month and 9 - 11 m old children (Skau et al., 2014). In Lao PDR, a dietary dataset that met the inclusion criteria was not available. Instead, a dietary survey was conducted from June to July 2012 on representative samples of six target populations (n=600) in an area at high risk of micronutrient deficiencies where intervention programmes were being planned (Saravane District).

In all countries, we processed the dietary data to generate the dietary parameters used for the LP analyses. In addition, we obtained market survey data to determine the costs per 100g edible portion for all foods modelled; and either created (Cambodia and Lao PDR) or expanded local food composition tables. The collection of market survey data differed in each country. In Cambodia, Indonesia and Lao PDR, they were collected at one point in time from markets (n=3), retail stores (n=3) and supermarkets (n=3) in one urban centre (i.e., Phnom Pen, Bandung and Salavan city, respectively). In Thailand, data from the Ministry of Commerce's website were sourced and converted into edible portions using local yield factors (unpublished, Institute of Nutrition, Mahidol University). In Vietnam, they were collected between June and September 2012 in seven locations representative of the different ecological zones, in Vietnam, and from five local markets or grocery stores in each location. We entered the dietary parameters and food cost data into the software programme 'Optifood'. Mean body weights were used to estimate average energy requirements, using the 2001 FAO/WHO/UNU algorithms (Food and Agricutural Organization, 2001), assuming sedentary physical activity levels for adults (physical activity level = 1.55).   For breastfed infants, a specific daily quantity of breastmilk was included in all modelled diets, which, for 6-8 m, 9-11 m and 12-23 m old children, in Cambodia, Indonesia and Lao PDR, were 590 g/d, 541 g/d and 494 g/d, respectively; and in Vietnam they were 667 g/d, 567 g/d and 400 g/d, respectively. In Thailand, the daily intake of breastmilk modelled for 6-8 m and 9-11 m olds were 607g/d and 557 g/d, respectively; and breast milk was not included in the models for 12-23 m olds. We ran the 'Optifood' analyses to identify, for each target population, problem nutrients (i.e., the nutrient's requirement was not achieved, in any modelled diet, using local foods as currently consumed) and to select sets of FBRs that would improve dietary adequacy at the population level in each country. The Ethics Committee of the London School of Hygiene & Tropical Medicine, UK approved the data analyses undertaken in this study.

Dietary assessment methods

In all countries, except Lao PDR and Vietnam, we used individual 24-hour dietary recalls (24-HR). In Vietnam, we used individual 24-HRs, for the child target populations; however, for the women, we calculated their individual food intakes from household 24-HRs using a consumption coefficient based on the adult energy equivalent. This coefficient was the ratio of the recommended dietary energy allowance for adult pre-menopausal women to that for 18-year old adult males. These coefficients ranged from 0.78 to 0.96, depending on the age and body weight of the woman. In Lao PDR, we collected semi-quantitative 7-day 24-HRs, in which women recalled the food and beverages consumed by themselves and their child each day for seven consecutive days. Food portion sizes were estimated by asking groups of women (n≥20 woman per food item) to show the quantity of each food consumed per meal, when they or their child consumed it, using food models of real foods.

Data analyses

We analysed the data, using linear programming analyses, in 'Optifood'. In all countries, we used an application created in MS-Access to derive the dietary parameters used in the LP analyses. In this application, the food intakes, for each target population, were adjusted to seven days by multiplying the grams of each food consumed by seven divided by the number of days of dietary intake recorded. Percentiles, for the number of servings per week from selected food groups and food sub-groups, were calculated. The LP model minimum and maximum constraint values selected, for each food group and food sub-group, were the 10th and 90th percentiles. The serving sizes, for individual foods, were median amounts consumed per day by consumers in each target population. The LP model minimum constraint values, for foods, were zero servings per week and the maximum constraint values were defined by the percentage of consumers, in each target population, as described elsewhere (Skau et al., 2014). We also adjusted these model parameters, when necessary, to ensure consistency across the model constraint values and across food serving sizes of similar foods; and in Thailand, to correspond with the food frequency data collected in their survey.

In the analyses, we ran three modules, in ‘Optifood’. In Module I, we checked if a series of modelled diets were realistic, and modified model parameters until the LP models selected realistic diets. Once satisfied that modelled diets were realistic, the analyses were done in modules II and III as described elsewhere (Daelmans et al., 2013) and summarised in **Table 1**.

[Insert Table 1 about here]

In brief, in Module II, the nutritionally ‘best diet’ for each target population was selected. The objective function for this model aims to come as close as possible to achieving the 2004 WHO/FAO target population-specific Recommended Nutrient Intakes (RNIs) for protein and 11 micronutrients (i.e., Ca, Fe, Zn, B1, B2, B3, B6, B12, folate, vitamin C and A) (FAO & World Health Organization, 2004)(WHO/FAO/UNU Expert Consultation, 2007). In the rare cases, when the modelled diet achieved all RNIs, ‘Optifood’ ran a second model. In this model, diet cost was minimised with additional constraints that ensured the selected diet achieved the RNIs for these 12 nutrients. Based on the food patterns of the Module II ‘best diet’, we selected individual FBRs for further testing in Module III. These FBRs included food groups (e.g., 7 servings/w of legumes), food sub-groups (e.g., 7 servings/w of green leafy vegetables) and foods (e.g., 2 servings/w of chicken liver). The selection criteria were: (1) the number of servings per week selected in the Module II nutritionally ‘best diet’, for a food group, exceeded the observed population median; and (2) a food or food sub-group contributed ≥5% of at least two nutrients in the Module II nutritionally ‘best diet’. Users, in each country, could also test additional FBRs if desired. In Module III, we ran 24 LP models for each FBR tested. For each of the 24 modelled diets, the content for one of the 12 nutrients of interest was maximised (i.e., n= 12 modelled diets that each had the highest level possible of one nutrient - best-case scenario nutrient levels). For the other 12 modelled diets, the nutrient content was minimised (i.e., n= 12 modelled diets that each had the lowest level possible of one nutrient - worst-case scenario nutrient level modelled diets). These diets (n=24) simulated the highest and lowest possible intake values predicted, for each of the 12 nutrients, in the population's intake distribution. Multiple Module III analyses were run; first without any FBR constraints (baseline diet) and then again with one or more FBR constraints for each FBR tested to ensure each modelled diet adhered to the FBRs being tested (e.g., each modelled diet would have seven fruits/w when a FBR for one serving/d of fruit was tested). Baseline best-case scenario results from Module III confirmed problem nutrients (i.e., a nutrient that did not achieve 100% of its RNI when the objective function maximised only this nutrient). Comparisons of worst-case scenario results, using nutritional and cost criteria, identified the best sets of FBRs for each target population. The nutritional criteria were the number of nutrients that had a worst-case scenario value ≥65% of its RNI, for the lowest number of individual FBRs in its set. This criterion was selected because a low percentage of the population would be at risk of inadequate intakes if its lowest nutrient intake value (simulated) of the nutrient intake distribution was at ≥65% of its RNI i.e., close to the estimated average requirement. This criterion defined dietary adequacy in this study. After testing each individual FBR, up to eight FBRs were selected for systematic analyses, whereby every combination of the set selected were tested in Module III (i.e., if eight FBRs were systematically combined then 247 combinations of FBRs were tested). We compared these sets of FBRs to select the best set(s) based on the above criteria, the minimised cost and perceived acceptability (subjective judgement) or alignment with local/national sets of recommendations.

In all models, constraints were placed on the simulated 7-day diet's food consumption patterns (i.e., minimum and maximum constraints on the number of servings/w selected of individual foods, food sub-groups and food groups) and energy content (equal to the average energy requirement of the target population) to ensure realistic and comparable modeled diets (see constraints in Table 1).

Results

Problem nutrients

The number of problem nutrients ranged from zero for 12 - 23 m olds in three countries, to six for pregnant women in Cambodia (**Table 2**). The 12 - 23 m old target population had the lowest numbers of problem nutrients overall (0 - 3, depending on the country) and the pregnant women had the highest numbers of problem nutrients (3 - 6, depending on the country). Women of reproductive age, especially pregnant women, tended to have a higher number of problem nutrients than the children, although not in Lao PDR.

[Insert Table 2 about here]

Comparing the countries, Vietnam had the lowest number of problem nutrients for children, and Lao PDR had the lowest number of problem nutrients for women of reproductive age. For Cambodia, if liver was not included in the models, the number of problem nutrients increased substantially (i.e., 5, 5, 3, 5, 6 and 4 problem nutrients for 6 - 8 m olds, 9 - 11 m olds, 12 - 23 m olds, adolescent girls, pregnant women and non-pregnant and non-lactating women). The survey participants did not report consuming liver. However, liver is available and consumed in Cambodia, so we ran two series of analyses (with liver and without liver). The serving size used for liver in these models were 10g (6-8 m olds), 11g (9-11 m olds), 20g (12-23 m olds) and 30 g (non-pregnant women). The maximum constraint level on the number of servings per week was four for children and three for the non-pregnant women. Liver was not included in the models for pregnant women. For inter-country comparative purposes, only the Cambodian data including liver is presented here (in Table 2), because liver was included in models for all other countries even though rarely consumed in most countries.

There were no marked inter-country differences in the types of problem nutrients found. The most common problem nutrients across all countries and target populations were calcium and iron (i.e., 18 of 24 target populations). For children, zinc was also a common problem nutrient (10 of the 15 child target populations); and for women, folate (6 of 9 target populations) and riboflavin (5 of 9 target populations) were common problem nutrients. Only vitamins C and B_{12} were not problem nutrients for any target population; and thiamine, niacin and vitamin B6 were problem nutrients for only one target population per nutrient (Table 2).

Food patterns of the nutritionally best diets

For all target populations across all countries, the number of servings per week of vegetables selected, in the nutritionally best diets, increased compared with observed median frequency levels, and they were often at the upper model constraint levels (**Table 3**). Likewise, for most target populations, the number of servings of meat, fish, eggs (MFE), dairy products and legumes selected in the nutritionally 'best diets' increased compared with observed median frequencies; and for MFE and legumes, they often were at the upper model constraint levels. The one exception was for the 12-23 m old children in Vietnam, where the number of servings of MFE selected in the nutritionally 'best diet' was lower than the observed median frequency because the Module II objective function minimised diet cost.

[Insert Table 3 about here]

For children under 12 months of age, the number of servings of grains generally decreased compared to median observed levels (7 of 10 target populations), whereas for 12 - 23 m olds and women the pattern was not consistent. For fruits, the number of servings selected, in the nutritionally best diets, generally increased across all target populations, in Cambodia and

Vietnam, but they decreased or stayed the same as the median for some target populations in Lao PDR, Thailand and Indonesia (Table 3). Roots were not consumed by 11 of 24 target populations, but when they were consumed they generally increased (8 of 13 target populations) or remained unchanged from the observed median intakes (4 of 13 target populations; Table 3).

Can realistic combinations of local foods ensure dietary adequacy for the target populations

The results showed that FBRs, using locally available foods and respecting observed food patterns (including liver in Cambodia), will likely ensure population level dietary adequacy for between 5 and 10 nutrients, depending on the target population (**Table 4**). Iron and calcium were often well below 65% of their RNIs (worst-case scenario Module III diets), suggesting it will be difficult to ensure dietary adequacy, for these nutrients, using amounts of local foods typically consumed. In contrast, vitamins C, B_6 and B_{12} achieved adequate levels across all target populations. For children, iron, zinc and calcium were the nutrient requirements that were the most difficult to achieve using local foods (15, 11 and 9 of the 15 target populations, respectively, did not achieve them), followed by thiamine and niacin (5 of the 15 target populations each) and folate (2 of 15 target populations). For women, dietary adequacy for calcium, iron, folate and riboflavin were the most difficult to ensure (9, 8, 8 and 7 of the 9 target populations, respectively, did not achieve them) followed by thiamine (3 of 9 target populations), niacin (2 of 9 target populations) and vitamin A (1 of 9 target populations). The number of nutrients for which adequacy was ensured was higher for children than women (i.e., 78% vs. 22% of target populations achieved adequacy for ≥8 nutrients for the children and women, respectively); and the number of nutrients for which dietary adequacy was ensured was lower in Lao PDR than in the other countries (Table 4). In Lao PDR, but not in the other countries, the worst-case scenario values for thiamine were

<65% RNI across all target populations; and the vitamin B6 worst-case scenario values were <65% RNI for pregnant and lactating women.

[Insert Table 4 about here]

The food-based recommendations selected for each target population

The number of individual FBRs, in each set of general over-arching FBRs selected for the target populations, ranged from five (women in Cambodia and Lao PDR, and children in Thailand and Vietnam) to seven (women in Vietnam), with the other three groups having six recommendations. For all target populations, the sets of FBRs included meat, fish and/or eggs and vegetables, especially green leafy vegetables. Fruits were included in the general set of FBRs for all women target populations and for all child target populations, except in Cambodia. The other FBRs included within one or more of these eight sets of FBRs were legumes/soy (n=2 target populations), dairy products (n=2 child target populations), liver or organ meats (n=7 target populations), pork (n=3 target populations) and eggs (n=2 target populations). These FBRs hypothetically would ensure dietary adequacy at the population level for between four and eight nutrients, for children, and between three and eight nutrients for women. Amongst both child and women target populations, dietary adequacy was lower in Lao PDR than in the other three countries (Table 5).

[Insert Table 5 about here]

Discussion

The results from this study suggest it will be difficult to ensure a low percentage of women and young children in SE Asia are at risk of inadequate intakes of micronutrients, using interventions focused on only modifying current dietary patterns without addressing the lack of access to nutrient-dense foods. For children, dietary adequacy for calcium, iron and zinc, and for women, dietary adequacy for calcium, iron, riboflavin and folate, are most difficult to ensure using realistic FBRs. On the other hand, our results suggest FBRs, if adopted, will ensure a low percentage of the target populations are at risk of inadequate intakes for between six and 10 nutrients, depending on the target population, especially for vitamins A, C, B6, B12, thiamine and niacin. The exception was Lao PDR where FBRs, if adopted, only ensured dietary adequacy of four to seven nutrients, depending on the target population. In the Laotian modelled diets, the contents of thiamine (women and children), niacin (children) and vitamin B6 (women and 12 - 23 m old children) were also low. Based on these results, the relatively high prevalence of stunted childhood growth reported across SE Asia, especially in Lao PDR, is not surprising (World Health Organization, 2017).

Two factors might account for these differences across countries. In Lao PDR, the dietary data came from a district with high rates of under-nutrition, as compared with other countries, where we used national level dietary data. Secondly, in Lao PDR, but not in other countries, glutinous rice (sticky rice) is the staple food, and their traditional rice processing practices destroy the water soluble vitamins in it (Barennes et al., 2009). Alternative factors, such as the number of foods included in the models, nutrient values in food composition tables, the types of foods modelled or constraints set on their maximum weekly amounts (in g) are less likely to account for the across country differences observed. Future studies should repeat the analyses by region and socio-economic groups to understand the extent to which national level FBRs can be generalised to different regions or socio-economic groups.

Our results also suggest that women of reproductive age and young children, in SE Asia, are at risk of inadequate intakes of calcium, iron, zinc (only young children), thiamine (Lao PDR) folate (only women) and riboflavin (only women). Unfortunately, a paucity of biochemical evidence exists at the national level to confirm these results. The prevalence of anaemia is moderate to high in Cambodia, Thailand and Vietnam (WHO/CDC, 2008). However, iron deficiency usually accounts for only 51% of cases of anaemia, in SE Asia (Wieringa et al., 2007), because haemoglobinopathies are common. Evidence to support our findings, for zinc, comes from studies showing zinc deficiency is common among young children in rural areas of Cambodia, Indonesia and Vietnam (Laillou et al., 2012)(Sandjaja et al., 2013)(Anderson et al., 2008). A paucity of data exists on the prevalence of deficiencies of folate, riboflavin, niacin and thiamine in the SE Asian region, which, from our results, needs further investigation A valid biochemical indicator, for estimating the prevalence of calcium deficiency, does not exist (Gibson, 2005).

Our results suggest that it will be difficult to decrease the percentage of women of reproductive age at risk of inadequate micronutrient intakes, using FBRs that only modify current dietary patterns. These results are in agreement with empirical data showing women from low income countries are at a high risk of inadequate micronutrient intakes (Torheim, Ferguson, Penrose, & Arimond, 2010). What was surprising; however, was our models suggest women of reproductive age are at higher risk of inadequate dietary intakes than young children are. In countries where we modelled the diets of both women and children, fewer nutrients achieved dietary adequacy for women compared with children. These differences were not the result of inter-group differences in the number of foods modelled in the maternal compared with children's diets. For example, in Cambodia and Vietnam, the number of foods modelled in the children's diets was higher than maternal diet i.e., 45 - 48 vs. 25 - 58 foods in Cambodia and 78 vs. 58 - 87 foods in Vietnam, depending on the target populations. Instead, women, in SE Asia are perhaps at higher risk of inadequate nutrient intakes than breastfed children are, because breastmilk is an important source of energy and most nutrients, as was shown in our modelled diets of breastfed children (data not shown). They also point to a need to focus on all women of reproductive age, and to address multiple micronutrients instead of just iron and folate, for pregnant women, as is currently done (Deitchler, Mason, Mathys, Winichagoon, & Tuazon, 2004). Improving maternal micronutrient status is also critical, for breastfed children, as it influences the micronutrient content of breastmilk (Allen, 2005).

The similarity of foods selected for FBRs across all five countries suggest that similar strategies and recommendations are required across the region. Amongst the FBRs, the most common foods to recommend, for ensuring dietary adequacy, are fruits, vegetables (including green leafy vegetables) and MFE. Within the MFE food group, chicken liver is particularly important to ensure dietary adequacy at a low cost, and fruits and vegetables are excellent sources of vitamin A and other vitamins. These results concur with a review endorsing liver as an acceptable food source of iron and zinc for infants (Krebs, 2007). While there are concerns regarding it's potential toxicity when consumed daily (Allen & Haskell, 2002), liver is likely safe for consumption in small, infrequent amounts (1-2 times per week). Liver is more affordable than red meat for the majority of families in SE Asia. These results also underscore the importance of including animal source foods in complementary feeding diets to ensure dietary adequacy, as reported by others (Gibson, Yeudall, Drost, Mtitimuni, & Cullinan, 2003) (Krebs, 2014)(Whaley et al., 2003).

Our results suggest FBRs alone will not ensure dietary adequacy for all children or women of reproductive age in SE Asia without the use of fortified products. Similar results have been shown in other countries for young children (Fahmida & Santika, 2016), including the United Kingdom (Vieux et al., 2016). In our analyses (data not shown), dietary adequacy, for young children, is achievable when the set of FBRs includes a recommendation for the consumption of fortified foods (Thailand) or multiple micronutrient nutrient powders (3-4 sachets/w in Cambodia, Indonesia, Lao PDR and Vietnam). Whilst MMPs have been shown to have a positive effect on children's iron status (De-Regil, Suchdev, Vist, Walleser, & Peña-Rosas, 2013), increased diarrhoea and respiratory morbidity have been described in children receiving MMP in a recent study in Pakistan (Soofi et al., 2013), linked to the inclusion of iron in it (Gera & Sachdev, 2002). In addition, the acceptability MMPs may depend on local beliefs about its health benefits. Organoleptic changes in foods to which MMP was added were reported by over 40% of participants in a trial of MixME™ in rural Lao PDR (Kounnavong et al., 2011). The affordability or acceptability of fortified infant products may also limit their uptake, highlighting the need in SE Asia to increase access to affordable and acceptable nutritious foods or products

The current study used nationally representative dietary data combined with a rigorous and objective mathematical modelling method to determine whether realistic FBRs are likely to ensure dietary adequacy for 6 – 23 m old children and women of reproductive age in SE Asia and to select a set of FBRs to meet the nutrient needs for these target populations. The strength of dietary modelling is that it can create hypothetical scenarios to help inform decisions and future research directions. However, conclusions are dependent on the quality of the data used to define model parameters, especially the food composition values, RNIs and food serving sizes (including breast milk). The nutrient values imputed from other food composition tables may or may not correspond with nutrient contents in SE Asian foods. For children less than 12 m of age, most RNIs are based on adequate intakes instead of estimated average requirements, which may over-estimate actual nutrient requirements (Gibson, 2005). Nevertheless, these analyses highlight the need for research to define the extent of multiple micronutrient deficiencies in SE Asia and then to develop and evaluate realistic intervention strategies that will increase access to affordable nutritious foods for women and young children.

In conclusion, our results suggest whilst FBRs that modify existing food consumption patterns can improve diet quality, it will be difficult to reduce the percentage of SE Asian women of reproductive age and young children at risk of inadequate intakes of multiple micronutrient to low levels using locally available nutritious foods alone in quantities typically consumed. Future studies should evaluate the biochemical status of multiple micronutrients in children and women of reproductive age, because our modelling results suggest multiple micronutrient deficiencies may be common. Intervention strategies need to address the lack of access to nutrient-dense foods, including healthy fortified products. Further studies should repeat the analyses for different sub-populations in SE Asia to identify the sub-populations to whom conclusions can be generalised. Empirical intervention trials also need to confirm the acceptability of the FBRs and these hypothetical results.

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Table 1: Summary, for Module II and Module III, its purpose and the linear programming models run in each module

	Objective Function	**Model Constraints**	**Purpose**
Module II[a]	Minimise the deviations below the WHO/FAO RNI[30, 31] for each nutrient, assuming moderate bioavailability for zinc and 10% absorption for iron	1. Energy content = energy requirement 2. Number of servings of each food ≥ specific value 3. Number of servings of each food ≤ specific value 4. Number of servings of each food group ≥ specific value 5. Number of servings of each food group ≤ specific value 6. Number of servings of each food sub-group ≥ specific value 7. Number of servings of each food sub-group ≤ specific value	Select the nutritionally best diet; where its nutrient content comes as close as possible to achieving the RNIs of each nutrient modelled
Module II[a]; if the RNIs for all nutrients are achieved	Minimise the total cost of the diet	1. Energy content = energy requirement 2. Number of servings of each food ≥ specific value 3. Number of servings of each food ≤ specific value 4. Number of servings of each food group ≥ specific value 5. Number of servings of each food group ≤ specific value 6. Number of servings of each food sub-group ≥ specific value 7. Number of servings of each food sub-group ≤ specific value	Select the lowest cost nutritionally adequate diet. This model can only be run if a diet can be selected that achieves all the modelled nutrients' RNIs

		8. Content of each nutrient ≥ its RNI	
Module III[b]	Maximise the nutrient content for each of the 12 nutrients modelled (n=12 objective functions to select 12 modelled diets) Minimise the nutrient content of each of the 12 nutrients modelled (n=12 objective functions to select 12 modelled diets)	1. Energy content = energy requirement 2. Number of servings of each food ≥ specific value 3. Number of servings of each food ≤ specific value 4. Number of servings of each food group ≥ specific value 5. Number of servings of each food group ≤ specific value 6. Number of servings of each food sub-group ≥ specific value 7. Number of servings of each food sub-group ≤ specific value 8. Number of servings of each FBR tested ≥ specific value	To identify nutrients, which cannot achieve their RNIs in any modelled diet (n=12 maximised modelled diets) To test the food-based recommendation modelled (n=12 minimised modelled diets), using a criterion of ≥65% of its RNI

[a]One linear programming model used

[b]24 different linear programming models run in this module

Table 2: Comparison of problem nutrients across countries in modelled diets that did not include fortified foods

	6-8 m	9-11 m	12-23 m	Pregnant women	Lactating women or Adolescent girls[a]	Non-pregnant & non-lactating women
Cambodia[b]	Ca, Fe, Zn	Ca, Fe, Zn	Ca, Fe, Zn	B_1, B_2, Ca, Fe, folate, Vitamin A	B_2, Ca, Fe, folate	B_2, Ca, Fe, folate
Indonesia	B_3, Ca, Fe, Zn	Fe, Zn	None	NA[c]	NA	NA
Lao PDR	Ca, Fe, Zn	Ca, Fe, Zn	Ca	Ca, Fe, folate	Ca, Fe	Ca
Thailand	Ca, Fe, Zn	Ca, Fe, Zn	None	NA	NA	NA
Vietnam	Fe, Zn	Fe	None	B_2, Ca, Fe, folate	B_2, B_6, Ca, folate	Ca, Fe

[a] Lactating women in Lao PDR and Vietnam; and adolescent girls in Cambodia

[b]Liver was not consumed by Cambodian target populations, but was included in the models, for all groups except pregnant women in Cambodia

[c]NA - not analysed

Table 3: Comparison of the food patterns of the nutritionally best diet (Module II) across countries and target populations

	Food Groups	Cambodia servings/w	Indonesia servings/w	Lao PDR servings/w	Thailand servings/w	Vietnam servings/w
6-8 m	Meat, fish, eggs	21[a]	2[b]	16[a]	21[a]	21[a]
	Vegetables	14[a]	5[b]	4[a]	14[a]	14[a]
	Fruits	7[a]	0[d]	3[b]	1[d]	1[b]
	Grains	4[d]	7[c]	9[e]	15[b]	7[e]
	Legumes	NE[f]	2[b]	NE	NE	4[b]
	Roots	NE	0[c]	NE	NE	0[c]
	Dairy	NE	NE	NE	NE	4[b]
9-11 m	Meat, fish, eggs	21[a]	7[a]	19[a]	26[b]	21[a]
	Vegetables	14[a]	7[a]	14[a]	14[a]	14[a]
	Fruits	7[a]	3[b]	4[b]	0[e]	7[a]
	Grains	5[d]	10[d]	11[d]	21[c]	7[e]
	Legumes	NE	5[b]	NE	NE	7[a]
	Roots	NE	1[a]	NE	NE	3[a]
	Dairy	NE	NE	NE	NE	3[b]

12-23 m	Meat, fish, eggs	21^{a}	4^{b}	16^{b}	20^{b}	9^{d}
	Vegetables	14^{a}	7^{a}	11^{a}	14^{a}	21^{a}
	Fruits	5^{a}	0^{c}	3^{d}	13^{b}	0^{c}
	Grains	4^{d}	14^{e}	12^{e}	28^{a}	28^{a}
	Legumes	3^{a}	7^{a}	1^{a}	NE	7^{a}
	Roots	2^{a}	0^{c}	NE	NE	0^{c}
	Dairy	4^{b}	0^{c}	6^{b}	15^{b}	5^{b}
Pregnant women	Meat, fish, eggs	21^{a}	NA^{g}	21^{a}	NA	28^{a}
	Vegetables	28^{b}		49^{a}		35^{a}
	Fruits	14^{b}		14^{a}		7^{a}
	Grains	12^{d}		27^{b}		22^{b}
	Legumes	2^{a}		2^{a}		7^{a}
	Roots	3^{a}		NE		2^{a}
	Dairy	3^{a}		NE		7^{a}
Lactating women adolescent girls	Meat, fish, eggs	21^{a}	NA	21^{a}	NA	28^{a}
	Vegetables	21^{a}		49^{a}		35^{a}
	Fruits	14^{b}		14^{a}		7^{a}
	Grains	11^{b}		27^{b}		24^{b}
	Legumes	0^{c}		2^{a}		7^{a}
	Roots	7^{d}		NE		2^{a}
	Dairy	NE		NE		14^{a}

Non-pregnant & non-lactating women	Meat, fish, eggs	21[a]	NA	21[a]	NA	28[a]
	Vegetables	28[a]		49[a]		35[a]
	Fruits	13[a]		9[b]		7[a]
	Grains	11[b]		16[d]		21[c]
	Legumes	5[a]		1[a]		7[a]
	Roots	4[a]		NE		2[a]
	Dairy	4[a]		4[a]		7[a]

[a] value is above the observed median food pattern and equal to the upper food pattern constraint level

[b] value is above the observed median food pattern but below the upper food pattern constraint level

[c] value is equal to the observed median food pattern

[d] value is below the observed median food pattern but above the lower food pattern constraint level

[e] value is equal to the lower food pattern constraint level

[f] NE – not eaten

[g] NA – not analysed

Table 4: Comparison of the number of nutrients for which dietary adequacy (≥65%) was achievable using food-based recommendations (without new fortified foods) and the nutrients whose worst-case scenarios were <65% of their RNIs presented by country and target populations

Cambodia	Indonesia	Lao PDR	Thailand	Vietnam
		6-8 months[a]		
8	8	7	8	9
Ca, Fe, Zn	B_3, Fe, Zn	B_1, Ca, Fe, Zn	Ca, Fe, Zn	Fe, Zn
		9-11 months[a]		
8	8	6	8	10
Ca, Fe, Zn	B_3, Fe, Zn	B_1, B_3, Ca, Fe, Zn	Ca, Fe, Zn	Fe
		12-23 months[b]		
9	8	4	8	8
Fe, Zn	B_1, B_3, Ca or Fe	B_1, B_3, B_6, Ca, Fe, Zn, folate	B_3, Fe, folate	B_1, Ca, Fe
		Pregnant women		
6	Not analysed	4	Not analysed	6
B_2, Ca, Fe, folate, vitamin A		B_1, B_2, B_3, B_6, Ca, Fe, folate		B_2, B_3, Ca, Fe, folate
		Lactating women or Adolescent girls[c]		
7	Not analysed	5	Not analysed	8
B_2, Ca, Fe, folate		B_1, B_2, B_6, Ca, Fe, folate		B_2, Ca, folate

Non-pregnant & non-lactating women				
7	Not analysed	7	Not analysed	9
B_2, Ca, Fe, folate		B_1, Ca, Fe, folate		Ca, Fe

[a]Modelled for breastfed children

[b]Modelled for breastfed children for all countries except Thailand where breastmilk was not included in the model because of the low percentage of breastfed 12-23 m old children in Thailand

[c]Modelled diets for lactating women in Vietnam and Lao PDR and adolescent girls in Cambodia

Table 5: Comparison of the selected sets of food-based recommendations (FBRs) and the number of nutrients they ensured were adequate (≥65% RNI) for children and women by country

	Children[a]		Women	
	FBRs	**#S/w[b]**	**FBRs**	**#S/w**
Cambodia	Meat, fish or eggs	14	Meat, fish or eggs	21
	Pork	3	Pork	7
	Liver	2	Eggs	3
	Vegetables	14	Vegetables	21
	Green leafy vegetables	7	Fruits	14
	Fruits	7		
	Number of nutrients ≥65% RNI: 6-8 m=7; 9-11 m=8;12-23 m=8		Number of nutrients ≥65% RNI: Pregnant = 6; Adolescent=6; NPNL[c]=6	
Indonesia	Meat, fish or eggs	7	Not analysed	
	Liver	1		
	Vegetables, especially green leafy vegetables	7		
	Fruits	7		
	Soya Products	7		
	Number of nutrients ≥65% RNI:6-8 m=8; 9-11 m=7; 12-23 m=7			

Lao PDR	Meat, fish or eggs	14	Meat, fish or eggs	21
	Liver (1 serves for 6-8m)	1, 3	Liver	3
	Vegetables	7	Vegetables	49
	Green leafy vegetables	2	Green leafy vegetables	14
	Fruits	7	Fruits	7
	Dairy (12-23 m only)	14		
	Number of nutrients ≥65% RNI: 6-8 m=6; 9-11 m=4; 12-23 m=5		Number of nutrients ≥65% RNI: Pregnant = 4; Lactating=3; NPNL=6	
Thailand	Meat, fish or eggs (14 serves for 6-8 m)	14, 21	Not analysed	
	Liver	2		
	Vegetables	14		
	Fruits (7 serves for 6-8m)	7, 14		
	Milk (12-23 m only)	14		
	Number of nutrients ≥65% RNI: 6-8 m=8; 9-11 m=8; 12-23 m=8			
Vietnam	Meat or fish (14 serves for 6-8 m)	14, 21	Meat, fish or eggs	21
	Organ meats	2	Pork	7
	Green leafy vegetables	14	Eggs	7
	Fruits	7	Liver	1
	Legumes	7	Fruits	7
			Vegetables	35

		Legumes	7
	Number of nutrients ≥65% RNI: 6-8 m=8; 9-11 m=8; 12-23 m=6	Number of nutrients ≥65% RNI = Pregnant = 5; Lactating=5; NPNL=8	

[a]The food-based recommendations are for breastfeeding children

[b]#S/w – number of servings per week

[c]NPNL – non-pregnant and lactating women