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Journal:	*Public Health Nutrition*
Manuscript ID	PHN-RES-2019-1207.R1
Manuscript Type:	Research Article
Keywords:	Rice fortification, diets, nutritional adequacy, equity, Nepal
Subject Category:	9. Interventions

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Conclusions:

Consumption of purchased fortified rice improves adequacy and gender equity of nutrient intake, especially in non-rice growing areas.

Key words
Rice fortification; diets; nutritional adequacy; equity; Nepal;

List of abbreviations: AHS III, 2014-2015 Annual Household Survey III; AME, adult male equivalents; EA, Enumeration Area; EAR, Estimated Average Requirements; LBWSAT, Low Birth Weight South Asia Trial; MPA, mean probability of adequacy; PA, Probability of Adequacy; PSU, Primary Sampling Unit; RNI, Reference Nutrient Intakes; VDC, Village Development Committee; World Food Programme, WFP.

Introduction

Women's diets are deficient in multiple micronutrients across many low-income settings [1], and these deficiencies have negative effects throughout the life course. Before and during pregnancy, inadequate consumption of micronutrients adversely affects women's risk of maternal mortality, and their children's foetal growth and birth weight [2, 3]. Despite political commitments to address malnutrition, at least two billion people are estimated to suffer from micronutrient deficiencies globally [4].

In Nepal, according to Demographic Health Survey estimates, anaemia has risen in recent years, with prevalence reaching 41% in women of reproductive age (15-49 years). This is particularly concerning because anaemia is a major cause of maternal mortality, with a 25% reduction in the odds of maternal death associated with every 1g/dl increase in haemoglobin [5, 6]. Beyond anaemia, deficiencies of multiple micronutrients are highly prevalent in Nepal, and exist concurrently [7, 8]. Amongst pregnant women in the *Terai*, Jiang (2005) found high levels of micronutrient deficiencies, including vitamins A (7%), E (25%), D (14%), riboflavin (33%), vitamin B_6 (40%), B_{12} (28%), folate (12%), zinc (61%) and iron (40%). Meanwhile, more recent national survey estimates reported low ferritin in 27.6% of children 6 to 59 months, 18.7% of pregnant women and 14.2% of pregnant women, zinc and vitamin A deficiencies in 20.7 and 4.2% of children 6-59 months and 24.3 and 3% of non-pregnant women respectively [8].

The limited dietary data available from Nepal indicate that diets fail to provide adequate nutrients [9, 10]. Geniez *et al.* found that 34% of people in rural mountainous areas were both food poor (unable to access sufficient energy) and nutrient poor (unable to access sufficient micronutrients) while 24% were nutrient poor only [11]. Across Nepal, rice is consumed daily, in large quantities [9, 12], and forms the major source of multiple micronutrients [10, 12]. Realistic dietary recommendations based on locally available foods may be insufficient to meet nutritional gaps [13] and, for households who suffer from food insecurity, achieving nutritional adequacy by this means seems unlikely in the short term [14, 15].

Fortification of rice in Asia has emerged as a feasible way to improve nutritional adequacy (16-21). In Bangladesh, fortification of rice in social safety nets has begun, with very positive results (22). In Cambodia, evaluation of fortified rice in school meals found positive effects on cognition (23) and micronutrient status (24), though effects were limited by inflammation (25). Iron fortification of rice in school meals decreased anaemia significantly in Bangalore (26), Andra Pradesh (27) and Odisha (28, 29). Similar impacts were found in pre-school children in Brazil (30, 31) and the Philippines (32), and factory workers in Mexico (33). In Costa Rica mandatory rice fortification, together with other fortification efforts, has been associated with decreased anaemia, B_9 (folate) deficiency and neural tube defects (33, 34).

With this in mind, rice fortification in Nepal has been identified as a potential strategy to reduce micronutrient deficiencies. It can deliver micronutrients safely and cheaply, builds on existing infrastructure, and requires minimal behavioural change (19, 35, 36). The Government of Nepal, in partnership with the UN World Food Programme (WFP), intends to introduce fortified rice via Nepal Food Corporation (NFC) social safety nets in remote and food insecure districts, by establishing blending units in NFC rice mills. Later introduction of blending technology to private sector mills will enable fortified rice to also be available from wider markets. However, rice intakes and nutrient deficiencies in Nepalese diets, and the potential for rice fortification to address these deficiencies has not been explored. Furthermore, whilst we expect adequacy of fortified nutrients to increase with fortification, quantification of possible differential impacts in sub-groups – such as poorer populations and women – is needed to examine who will benefit the most from rice fortification in Nepal. Similarly a study modelling the micronutrient contribution of fortified foods in Afghanistan recommended that "*future research should … compare the contribution from fortified foods with* total *dietary intake .. to see if and how the gap is being filled*" (37). Thus, in this study, we model the potential impacts of rice fortification on nutritional adequacy of different population subgroups to investigate the equity impact and inform the rice fortification process in Nepal.

Methods

Between June and September 2015, we collected individual 24-hour dietary recalls to measure the diets of pregnant women, their mothers-in-law, and male household heads, in Dhanusha and Mahottari districts in Province 2 [38-42], as part of the Low Birth Weight South Asia Trial (LBWSAT) on antenatal nutrition [43, 44]. Around the same time (19 September 2014 to 16 July 2015) the third national Nepal Annual Household Survey (AHS III) was conducted [45]. This estimated 7-day household food consumption for a nationally representative sample of households. These two studies provide us with rich data sources to estimate the potential benefits, and potentially differential benefits, of rice fortification in different population sub-groups. The individual-level dietary data from LBWSAT contain data on men and pregnant and non-pregnant women, so we can model potential impacts of rice fortification with high precision, and can estimate the intra-household equity implications of rice fortification in Province 2, where underweight and anaemia is highest [46]. We compare this with the household-level annual survey (AHS III) to give a national picture, and to allow us to model potential impacts on adults and children, and in different geographies.

Sampling and field procedures

The detailed protocol and electronic data collection methods of LBWSAT have been described elsewhere [43, 47], as have the methods of measuring diets [38, 39]. Briefly, 24-hour dietary recalls were collected in 805 households in 80 clusters, but for this study we use the data from 128 households sampled in the 20 control clusters. Each cluster was defined as one Village Development Committee area (VDC, a geopolitical unit). Within each household three members were sampled (pregnant woman, mother-in-law and male household head), limiting our sample to traditional joint, male-headed households. Dietary recalls were repeated up to three times per person on non-consecutive days within a period of two weeks [38, 39). Portion sizes were estimated using a pictorial food atlas of portion sizes that was developed and validated locally [39].

The AHS III sampled 15 households in each of the 288 primary sampling units (PSUs) that were selected from a sampling frame of 4861 urban and 36191 rural enumeration areas (EA) using population proportional to size. Selected PSUs covered 65 of the 75 districts in Nepal and thus may be considered to be nationally representative, covering all agroecological zones and wealth groups. Using 2011 household census lists, 4360 households were randomly selected for interview. After describing the household composition using a roster, respondents were interviewed about their consumption of a list of foods and drinks, yielding a dataset with details of consumption of 60 foods. If an item was consumed in the preceding week, enumerators recorded the frequency (d/wk) and quantity (kg/wk from home production, purchase, or receipt in-kind) that the item was consumed [45].

Analysis of dietary data

In both datasets, we calculated proportion of households consuming rice and purchased rice, mean rice consumption (g/d) for each household member, and mean intake of purchased rice in the AHS III data. In the AHS III we used Adult Male Equivalents [48] to allocate household-level intakes to individuals. We calculated average daily nutrient intakes, using nutrient composition values compiled into a Nepal-specific food composition table (available on request) [39].

We estimated nutritional adequacy of eight micronutrients normally recommended for rice fortification [49]: vitamins A, B_3 (niacin), B_6 (pyridoxine), B_{12} (cobalamin), B_1 (thiamin), B_9 (folate), iron and zinc, plus three other micronutrients: calcium, B_2 (riboflavin) and vitamin C. Then, by substituting micronutrient values of unfortified rice with those of the WFP 2016 fortified rice specification [50], we quantified the potential nutritional increase from rice fortification in terms of PA for each nutrient, MPA of 11 nutrients, and equity of nutrient adequacy.

Nutrient levels in unfortified uncooked rice, the estimated levels of water-soluble B vitamins in unfortified cooked rice after applying a conversion factor of 1/0.36 = 2.78 for deriving dry weight, the WFP [50] and Bangladesh [51] fortified rice specifications, and those recommended by DePee at al [52], are provided in **Table 1**. Despite some evidence of loss of nutrients during washing and cooking of milled rice[53], we were not able to access estimates of losses in the Nepal context, where cooking method varies by region of the country. Hence we used uncooked rice nutrient estimates since the Nepal[54] and India[55] food composition tables (FCTs) provided only uncooked rice, FCTs vary widely in their estimates for rice, and the AHS III data provided consumption estimates of dry uncooked rice only, so introducing conversions to cooked rice would have introduced further error. Table 1 shows the figures used for uncooked rice and two alternative estimates of water-soluble B vitamins in cooked rice from figures in the Bangladesh[56] and USDA[57-59] food composition tables (converted to the dry weight). For B_6 and B_3 our estimates for raw rice lie in between the ranges of estimates of cooked rice from USDA and Bangladesh FCTs, whereas for B_1, B_2 and B_9 the cooked values are somewhat lower than those for raw rice.

[Insert Table 1]

Since only purchased rice is going to be fortifiable in the foreseeable future, we modelled fortification of purchased rice only, not home-grown rice. For LBWSAT data, we estimated the share of rice that was bought based on their self-reported ranking (1-5) of the importance of purchasing rice as their main rice source, assuming that this ranking was proportional (1=100% of rice bought; 2=80% bought, and so on).

Probability of adequacy was calculated using the 'probability approach' [60]. For LBWSAT, we estimated daily 'usual' intakes by transforming nutrient intakes to normal distributions using Box-Cox transformations [61], and calculating the Best Linear Unbiased Predictors to account for within- and between-person variance. For AHS III, daily usual intakes were simply 1/7 of weekly intakes. For both datasets, we calculated the Probability of Adequacy by comparing intakes (apart from iron for non-pregnant women) with known nutrient requirement means (EARs) and standard deviations [62-

[65]. We assumed low bioavailability of iron (at 5%, apart from pregnant women at 23%)[62] and zinc (18% men; 25% women; 23% children)[66]. When not available, we calculated Estimated Average Requirements (EARs) for all age groups and pregnancy status using reference nutrient intakes (RNIs) for each nutrient as follows: EAR = RNI x [(2 x CV / 100) + 1], and SDs as EAR x CV. We used US Institute of Medicine values for calcium (EARs and SD)[63] and iron (probability of adequacy)[64]. For zinc we used EARs from the IZiNCG study [66], and for all other nutrients we used FAO/WHO 2004 values [62] based on estimates of CV from WHO 2006 [67].

Sensitivity analyses

We repeated these analyses using micronutrients specified in the Bangladesh fortified rice standard as a sensitivity analysis of different fortificant blends. We did not model the Indian standard as this (optionally) contains riboflavin which is known to affect the colour, flavour and acceptability of fortified rice so is unlikely to be used in Nepal [68]. As the LBWSAT data were collected between June and September 2015 (which includes mango season), we report vitamin A intakes with and without mangos. The AHS III data were missing certain key food groups (notably green leafy vegetables and eggs). We conducted a sensitivity analysis to see how intakes changed when a daily 50 g portion of green leafy vegetables and 1 egg were added to the diet.

Since the AHS III analyses rely on Adult Male Equivalents to estimate individual intakes, we used LBWSAT data to measure the agreement between observed and predicted intakes for pregnant women, their mothers-in-laws and male household heads with and without adjustments for pregnancy, physical activity levels, and body weight. Bland-Altman limits of agreement were calculated as the mean kcal difference between observed and predicted intakes ±1.96 SD [69].

We also calculated the percentage of respondents whose micronutrient intake exceeded upper tolerable limits of the fortifiable nutrients [62].

Equity analyses

To estimate the potential gender equity impact of fortification in LBWSAT, we calculated the increase in PA from fortification for pregnant women and men, and differences between the two (difference-in-difference). Then, we tested whether the intercept of this difference-in-difference was significantly different from zero using linear regression models. To estimate the differential impact of fortification by regions in AHS III, we applied double hurdle regressions (Cragg's models) which account for the large number of zeros for people who have no fortification because they are home producers. The models assess the probability of benefiting from fortification in two equations (1) whether or not households have any improvements in MPA (determined by whether they purchase any rice), and (2) how much the MPA improved (determined by how much purchased rice is consumed). We report the conditional mean estimates of the mean difference in probability of adequacy comparing: all other provinces with province 3 (where Kathmandu is based), hills and mountains with *Terai*; and rural with urban areas. All analyses and reported SEs account for survey design, and were conducted in Stata SE 14 (StataCorp LP).

Results

Response rate and respondent characteristics

The LBWSAT sample included 150 households out of 199 eligible households visited (75% response rate) and we modelled potential effects of rice fortification on 128 households (1230 dietary recalls from 384 individuals) because 22 households had missing information on rice purchase. Prior analyses show no major differences in respondent characteristics between respondents and non-respondents [(41)]. AHS III data contain 4360 households with 5443 women aged 15-49 years and 3346 children aged 5-12 years. Characteristics of the households studied are given in **Table 2.**

[Insert Table 2]

In both LBWSAT and AHS III samples, women and men are poorly educated. Pregnant women from LBWSAT are younger (median age: 21 y), and mothers-in-law older (50 y), than the women of reproductive age in the AHS III sample (28 y). The LBWSAT data show that nearly half of households have members migrating overseas for labour, and perceived food insecurity and thinness (mid-upper arm circumference <23 cm) [70, 71] is prevalent, the latter particularly among pregnant women. Diets are insufficiently diverse, with over a third (42 to 38%) consuming less than the recommended five out of ten food groups on the first day of dietary recall [72].

Rice intakes

The rice intakes in LBWSAT plains population **(Supplemental Table 1)** and across Nepal in AHS III **(Figure 1)** show that rice is consumed regularly, by most people, and in high quantities, making it a promising candidate for fortification.

In the LBWSAT sample, boiled white rice made up the majority of the diet. Almost all (98%) households ate some rice over the three days of dietary recall, and 76% purchased some of their rice. Respondents consumed rice twice (1.8 times) per day amounting to a median cooked weight of 667 grams per day. Rice was occasionally consumed as fried rice, rice pudding, porridge ('*khichadi*' or '*jaulo*'), beaten rice, puffed rice, or as an ingredient in deep-fried snacks, but the mean frequencies of consumption (range: 0.01 to 0.10 times/d) were much lower than boiled rice. Beyond rice, wheat, consumed as an unleavened bread called '*roti*', and '*dal*' (lentil soup) were both consumed on average once per day.

Consistent with LBWSAT results, across Nepal nearly all AHS III households (99%) consumed rice in the preceding week (Figure 1).

[Insert Figure 1]

Per capita daily consumption was lower than LBWSAT figures, at (mean ± SD) 314 ± 170 g/d, and consumption of purchased rice was 149 ± 186 g/d. Whilst overall rice consumption was highest in the *Terai* Province 2 (where our LBWSAT sample was located), the results indicate that the mountains and urban areas would benefit most from fortification, since consumption of purchased rice was highest in these Provinces (Provinces 6, 5, 3 and 1).

Current micronutrient intakes and adequacy

In both samples, micronutrient intakes before fortification ('current' rows in **Table 3**) show diets are low in key micronutrients. Despite the different methods of estimation, micronutrient intakes were reasonably similar between LBWSAT and AHS III, though intakes were lower in AHS (see Table 3 'current'). In LBWSAT, nutrient intakes were highest amongst men, followed by pregnant women, and mothers-in-law ate least.

[Insert Table 3]

The same micronutrients that are consumed in particularly low levels are those that are not found in unfortified rice. Dehulled, non-parboiled, non-fortified rice provides no vitamins A or B_{12}, and very little of vitamins B_1 (thiamin), B_2 (riboflavin), iron, zinc, vitamin B_6 (pyridoxine) and somewhat higher levels of B_9 (folate) and B_3 (niacin) (see Table 1 and de Pee (2014) [49]). Our sensitivity analysis of adding a daily portion of 50g green leafy vegetables and one egg (since data were missing for these food groups in AHS) generated intakes more similar to the LBWSAT estimates. Vitamin B_{12} intakes were close to zero for all subgroups.

Probability of nutrient adequacy in the unfortified diets are shown in the 'current' bars in **Figure 2** (AHS III) and **Figure 3** (LBWSAT).

[Insert Figures 2 and 3]

Across both samples, diets with unfortified rice are highly deficient in multiple micronutrients, notably vitamins B_{12}, B_9 (folate) and A, iron, and zinc for all household members studied. In the unfortified diets of pregnant women, only vitamins B_3 (niacin), B_6 (pyridoxine) and B_1 (thiamin) exceeded 50% PA, while vitamins A, B_9 (folate), iron and zinc all lie below 10% PA and vitamin B_{12} has a PA approaching zero (Figure 3). Whilst deficiencies in the diet are less extreme for male household heads and mothers-in-law, PAs below 30% are found for vitamin A, iron, zinc, and PA for vitamin B_{12} is, again, close to zero. Similarly, unfortified AHS diets are highly deficient in vitamins B_{12}, A, B_9 (folate) and iron.

Potential micronutrient intakes and adequacy after rice fortification

All population subgroups analysed show large increases in micronutrient intakes after fortification, with much higher increases when only rice-purchasing households are analysed. Table 3 provides daily nutrient intakes when all purchased rice in the diets is fortified, averaged across all households (labelled 'full sample') and in rice-purchasing households (labelled 'buyers only'). This shows how potential effects will be constrained by households who do not purchase rice and therefore do not benefit from fortification. Fortification with the Bangladesh standard premix **(Supplemental Table 2)** leads to broadly similar, though slightly lower, intakes than consumption of the WFP standard except for B_3 (niacin) and B_6 (pyridoxine), which are not in the Bangladesh standard.

Probability of Adequacy (PA) in the 'current', 'full sample' and 'buyers only' diets are given for AHS women and children (Figure 2) and LBWSAT household members (Figure 3). After substituting normal rice with fortified rice using fortificant levels in the 2016 WFP specifications, dietary deficiencies of key nutrients are largely resolved in rice-purchasing households. Smaller but nevertheless substantial improvements in mean adequacy levels are found when non-rice purchasing households (who would not access fortified rice) are included in the population average. Amongst rice purchasers in all population subgroups, probability of adequacy exceeded 90% for B_3 (niacin), B_6 (pyridoxine), B_1 (thiamin), B_9 (folate) and zinc after fortification. Vitamin A increased to >85% PA for AHS women, male household heads, and mothers-in-laws but was lower for pregnant women and children. After fortification of rice, the mean PA of iron did not reach 100% for any category of household member. Generally, the impact of fortified rice on iron adequacy was lowest for mothers-in-law, reflecting their lower consumption of rice than other family members described earlier. However, if we assume iron bioavailability is higher due to the presence of fortified rice in the diet (15% rather than 5%), we see much larger increases in iron PAs on average in the full AHS sample (women: 77%; children: 87%) and especially in rice-buying AHS households (women: 95%; children: 99%).

For populations reliant on groundwater such as those in the *Terai*, our estimates of iron adequacy are uncertain due to the wide variance in estimates of iron concentrations in groundwater across the region in Nepal[72-75] and Bangladesh[76-78]. Sensitivity analyses of adding the lowest estimate of 0.04 mg/d, based on lower bound estimate of 0.02 mg/L from Kannel (2008) in the Kathmandu valley [74] and a water intake of 2 L/d[79] would result in almost zero change in probability of adequacy estimates. On the other hand, adding a high estimate of 42 mg/d from very high iron contamination areas in Bangladesh[77] would result in pregnant women, men, and women all having an PA of 1 if 15% bioavailability is assumed, and all pregnant women and men having an iron PA of 1, and non-pregnant women having a PA of >0.85 from water intakes alone if 5% bioavailability is assumed.

The risk of exceeding the upper tolerable levels will be high if consuming 42 mg/d from water intakes, since the upper level cut-off is 45 mg/d. However, the probability of such high intakes is probably low since most of the Nepal estimates fall well below this one at 0.05-10.81 mg/L from the eastern Terai[72], 0.3 to 19.5 mg/L from central Terai[75], 0.02 to 1.24 mg/L[74] and 1.9mg/L[73] from the Kathmandu valley. Therefore, although iron contamination of water is more likely in the *Terai*, people tend to grow more rice and are less likely to consume fortified rice in this region. Nevertheless, monitoring of iron contamination, water intakes, and serum ferritin levels, may need to accompany implementation of rice fortification programmes in the future.

Increases in Mean Probability of Adequacy (MPA) with fortification of rice were constrained by deficient nutrients that are not included in the fortificant premix such as calcium, vitamins B_2 (riboflavin) and C. In rice-purchasing households MPA increased by around 30 percentage points (pp) for all groups, to around 70% for women and children and 80% for men.

We assessed risk of the upper tolerable intake levels (ULs) and found no issues. We however noted that, to avoid exceeding UL for niacin, niacinamide will need to be used (as required by the WFP specification) in fortification because it has a much higher UL (900 mg/d) than nicotinic acid (35 mg/d).

Analysis of the impact of fortification on gender equity **(Figure 4)** shows that women benefit from fortification relatively more than men.

[Insert Figure 4]

Increases in adequacy were significantly higher in women than men for vitamins B_9 (folate) (41pp; p<0.001), B_3 (niacin) (23pp; pp<0.001), B_6 (pyridoxine) (14pp; p<0.001), B_1 (thiamin) (8pp; p<0.01) and overall MPA (2 pp; p<0.05), whereas, for Vitamins A, B_{12} and zinc increases were significantly higher for men (25, 14 and 18 pp respectively), and increase in iron adequacy was similar.

Regional differences in potential impact of fortification are shown in **Table 4.**

[Insert Table 4]

We find minimal differences across provinces, but significantly larger improvements in MPA in hilly (8pp; p<0.001) and mountainous (7pp higher; p<0.05) than the plains, and 5pp (p<0.05) lower improvements in rural than urban areas.

Our test of agreement between observed intakes and intakes predicted by the application of AMEs **(Supplemental Table 3)** indicates that the application of AME does not result in large bias (range: -84 to +66 kcal) but does tend to overestimate pregnant women's intakes, underestimate men's intakes, and gives wide limits of agreement. This overestimation is greatly increased if AMEs account for pregnancy status. Incorporation of self-reported activity levels to adjust AMEs also does not appear to increase agreement between observed and predicted intakes.

Discussion

To our knowledge, this is the first study to model the potential effects of rice fortification on probability of micronutrient adequacy and to examine the equity implications of a rice fortification intervention. We find that unfortified diets are inadequate in Nepal, and that rice is consumed in high quantities, making it a good candidate for fortification. Nutrient inadequacy is particularly high for vitamins B_{12}, A, B_9 (folate), iron and zinc (all potentially fortifiable in rice) and also calcium and riboflavin. Different geographical areas are likely to benefit differentially from rice fortification; consumption of fortifiable purchased rice being highest in the remote Province 6 and generally high in the mountains and urban areas where rice is not grown. Perhaps unsurprisingly, we find that replacing normal purchased dehulled, not-parboiled polished white rice with fortified rice, as per the mid-point between minimum and maximum WFP specifications, would resolve dietary deficiencies in all population subgroups analysed for all fortified micronutrients in rice-purchasing households, except vitamin B_{12} and iron in pregnant women (if higher bioavailability is assumed). However, the equity implications are arguably more interesting and important. Rice fortification is predicted to increase pregnant women's adequacies more than adult males for most nutrients. Due to higher intakes of bought rice, the nutritional adequacies of more remote hilly and mountainous populations are predicted to improve more in response to rice fortification than in the plains, as will adequacy in urban compared with rural areas.

Implications for addressing micronutrient deficiencies

The results indicate the WFP 2016 specification levels for rice fortification are generally appropriate and could address major nutrient gaps, though we could consider reducing levels of B_3 (niacin), which is already found in rice. For a location where rice consumption is 150-300 g/capita/d, De Pee et al 2014 [49] and 2018 [52] recommended the following fortification levels (mg/100g): iron (micronised ferric pyrophosphate), 7 (or if ferric pyrophosphate is combined with citrate and trisodium citrate, or possibly other solubilising agents, 4); folic acid (B_9), 0.13; vitamin B_{12} (cyanocobalamin), 0.001; vitamin A (palmitate), 0.15; zinc (oxide), 6; B_1 (thiamine mononitrate), 0.5; B_3 (niacin amide), 7; and B_6 (pyridoxine hydrocloride), 0.6. The WFP 2018 updated recommendation provides corresponding increases/ decreases per 100g with decreasing/increasing levels of rice consumption [52]. We found that the 2016 median WFP specification we tested broadly matched these new recommendations but had slightly elevated levels of most micronutrients.

For pregnant women, additional iron and Vitamin B_{12} from improved dietary quality and supplements would still be required to reach adequacy. Since the Nepal government distributes free iron/folic acid supplements for 225 days of pregnancy and early lactation, the shortfall in these micronutrients should be met among pregnant and lactating women that consume these supplements sufficiently. However, B_{12}, which is only found in animal-source foods, appears to be a problem nutrient, especially in the plains population. Although riboflavin (B_2) intakes are inadequate, we do not suggest adding riboflavin to the fortificant premix for Nepal, due to known colour changes in the fortified rice kernels which reduce consumer acceptability [68]. Whilst levels of fortificants recommended in fortified rice are safe, caution has been advised due to the association between consumption of fortified rice and hookworm infection [81]. This means that promotion of fortified rice, especially in schools, needs to be accompanied with deworming and public awareness campaigns promoting use of footwear and other hygiene and sanitation practices.

Micronutrient deficiencies in the Nepalese diet we investigated are similar to those found in mothers and young children in Bangladesh, although vitamin A, B_9 (folate) and zinc deficiencies were worse and vitamin B_{12} less severe in Bangladesh [82]. Our estimates suggest higher adequacy in pregnant women and other population subgroups in 2015 than those found for lactating mothers in urban Nepal in 2009 [10]. Nevertheless, the diets we studied are severely deficient and staple fortification is warranted.

One study in UK applied a similar modelling approach to ours using UK dietary consumption data. They simulated fortification of wheat flour and milk with vitamin D and analysed the effect upon adequacy of intake amongst at-risk population sub-groups. When wheat flour was fortified, the proportion estimated to have vitamin D intakes below United Kingdom Reference Nutrient Intakes fell from 93% to 50% without any individual exceeding Tolerable Upper Intake Levels [83]. In Vietnam, Laillou et al similarly used data from a national survey of women's diets to estimate the impact of different fortified foods upon dietary intake. They showed that rice fortified with iron, zinc and folic acid could increase intakes as a percentage of the RNI by 41% for iron, 16% for zinc and 34% for B_9 (folate), concluding that fortified rice was the most appropriate vehicle for fortification in that setting [84]. In 2013, the Global Alliance for Improved Nutrition (GAIN) developed a Fortification Assessment Coverage Toolkit (FACT) designed to help stakeholders collect, analyse, and synthesise standardised data on quality, coverage, and consumption of fortified foods. By assessing the amounts of fortifiable and fortified foods consumed, 'feasibility gaps' and 'fortification 'gaps' can be quantified to estimate potential of different fortified foods and the extent this potential is being fulfilled. This has been applied to inform fortification policy in Nigeria, Pakistan, Tanzania [85] and Afghanistan [37]. The limitation in this method is that it looks only at the micronutrient contribution of the fortified food and not at other dietary sources, a problem which is rectified in our approach.

The potential clinical significance of the increases in micronutrient adequacy that could result from consumption of fortified rice are wide-ranging, and include: improved iron [26], zinc [86], vitamin B_{12} [87], and vitamin A status [24, 88]; lower prevalence of anaemia [26-29, 32], beriberi [89], and neural tube defects [90]; and improved cognition [23] and physical performance [86].

Implications for reaching the poorest

Many farmers grow and consume their own rice, and it is not currently feasible to blend fortified rice kernels with home-grown rice in small-scale mills, so only rice milled commercially in large mills will be fortifiable in the foreseeable future, and only rice-buyers will benefit [36]. Our analyses indicate that rice-buyers are found across the wealth spectrum: urban areas (which includes poorer and wealthier households), and the hilly and mountainous areas where rice production is lower. Additional interventions are needed for households that do not buy much rice, especially in *Terai* areas where both home-production and micronutrient deficiencies are highest [46].

Of those that do purchase rice, fortification may benefit better-off households most. Voluntary fortification is likely to precede or preclude mandatory fortification, and the incremental price increase will likely deter poorer buyers from choosing it [91]. Also, the private sector may prefer to fortify and market more expensive rice varieties, and market its higher nutritional value, which would only be afforded by better-off consumers. One potential means by which rice fortification can benefit those who need it most will be to distribute fortified rice via social safety nets [91] as per the Government of Nepal's plan. If subsidised fortified rice is distributed through the Nepal Food Corporation, it could reach the most food insecure and inaccessible areas of the country. However, to reach the poorest in other areas, wider access to low-cost or subsidised fortified rice will be needed.

Our results also examine the potential for rice fortification to be a gender-sensitive intervention. We find that pregnant women in Province 2 are likely to see bigger improvements in their micronutrient adequacy from rice fortification than men, which could help address the gender gap in micronutrient adequacy. This may be because women tend to rely heavily on rice to meet their dietary needs [9, 10, 12, 92], and their diets comprise a higher share of starchy staples than men's [42], but also their diets are more deficient, so gains are easier to achieve. Of course, rice fortification is not a replacement for women's empowerment or behaviour change interventions aiming to improve women's dietary quality and equity of nutrient intake within households, but it would form a useful complement to such interventions.

Study limitations

Limitations of our study include our extrapolation to the entire population, since in the short to medium term only a small proportion of the population who purchase Nepal Food Corporation social safety net rice and WFP school meals programme recipients would actually benefit. To realise the benefits we predict, households would need all their purchased rice to be fortified. Also, families are likely to substitute unfortified home-grown rice with bought, fortified rice only when their grown rice has run out. This means that there may be benefits during the lean season (before rice harvest) in late- / post- monsoon but less benefit post-harvest in the winter when availability of fruits and vegetables is also limited at high altitudes. Having said this, the pre-harvest lean period is when additional intakes through fortification are most needed because multiple micronutrient serum concentrations (especially beta-carotene, B_6, B_9 (folate), and iron concentrations) are notably low [7].

In LBWSAT we estimated the share of rice that was purchased on the basis of self-reported ranking of the relative importance of purchase to meet the staple food needs. This application of a rule of thumb to assume the proportion of rice purchased is a source of error that we cannot quantify. Both LBWSAT and AHS III surveys were collected over a period of months (June to September 2015 for LBWSAT and September 2014 to July 2015 for AHS III) but neither survey covered all seasons of the year. This means that seasonal variation outside the periods sampled is not accounted for in our findings.

We have estimated mean intakes for men, non-pregnant women and children in the Annual Household Survey III using Adult Male Equivalents to allocate nutrients to household members as per energy requirements. The assumption that women are not pregnant is important because our results from Bland-Altman limits of agreement show that AMEs overestimate the intakes of pregnant women in particular. The AHS III dataset was missing eggs and green leafy vegetables and a relatively short list of 60 foods were reported, so our estimates of adequacy may be an underestimate. However, conservative sensitivity analyses, and comparison with LBWSAT results, show the same key trends: adequacy of diets drastically improves with fortification but Vitamin B_{12} (and iron for pregnant women) remain problem nutrients and mean probability of adequacy is constrained by unfortified nutrients such as riboflavin (B_2), calcium and vitamin C.

Our estimates are based upon uncooked rice nutrient values which have not been adjusted for losses during cooking. This means that there is some risk of overestimating intakes of vitamins B_1, B_2 and to a lesser extent B_9. However, in comparison with reported intakes from a slightly larger LBWSAT sample which used cooked rice values[42], our intakes from uncooked rice estimates from are very similar, indicating that the error introduced from using uncooked rice estimates is small.

Our LBWSAT dietary adequacy estimates for pregnant women and their families may not be generalisable to more wealthy and non-plains populations of Nepal, since Dhanusha and Mahottari districts fall in the second poorest grouping of districts in Nepal with Human Poverty Indices (HPI) of 41.7 and 44.8 respectively versus the national average HPI of 31.1[93] and inequitable intrahousehold food allocation is particularly prevalent in the plains [9, 42]. On the other hand, since the AHS III is a nationally representative survey, the findings from this study are generalisable to Nepal[45]. This means that the risk of exceeding upper limits of consumption are low even in wealthier households, except for the case of iron in scenarios where all rice consumed is fortified, pregnant women take daily iron supplements, and there is high contamination of ground water with iron.

Future research documenting individual dietary data from different age-sex groups across Nepal would help obtain a more precise estimate of the broader potential impact on nutritional adequacy.

Our results are from modelled scenarios, based on assumptions about consumption levels, requirements (infection, activity levels, nutrient retention), and interactions between nutrients. Further research to measure these could inform future models and improve their accuracy. Rather than conducting more trials under experimental conditions, we recommend careful evaluation of rice fortification through Nepal Food Corporation and/ or the School Meals Programme in Nepal, particularly effects on: uptake by the private sector; wider dietary changes; biochemical indicators of micronutrient levels (especially niacin), children's health, and school performance.

We conclude that fortification of rice using the WFP specification, in combination with other health and nutrition programmes, presents an opportunity to contribute to the reduction of micronutrient deficiencies and also to reduce inequalities in micronutrient allocation in Nepal.

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Table titles

Table 1. Micronutrient levels in unfortified uncooked rice and in dry weight of cooked rice from Bangladesh and USDA food composition estimates, and World Food Programme 2016, Bangladesh, and DePee fortificant specifications for fortified rice

Table 2. Socio-demographic and health characteristics of LBWSAT and national Annual Household Survey III samples

Table 3. Mean dietary nutrient intakes, with and without fortification of purchased rice, using WFP specifications

Table 4. Regional comparison of the difference in women's mean probability of adequacy with and without fortification

Supplemental Table 1. Daily frequency of consumption of rice dishes, other staple foods, and other common foods from LBWSAT sample

Supplemental Table 2. Mean dietary intakes of micronutrients that are included in Bangladesh rice premix, after fortification of purchased rice using Bangladesh standards

Supplemental Table 3. Agreement between observed and predicted daily energy (kcal) intakes from LBWSAT

Figure legends

Figure 1. Mean intakes of all rice and purchased rice by province, ecological zone, rural / urban, women and children.

Using Annual Household Survey 2014-15 data.

Percentage of households purchasing rice is provided below each category.

Figure 2. Probability of micronutrient adequacy of women and children in Nepal, with and without rice fortification

Using Annual Household Survey 2014-15 data.

'Current' = based on unfortified diets of total population (women *n*=5443; children *n*=3346)

'Full sample' = based on total population when bought rice is fortified with WFP mid-point values (women *n*=5443; children *n*=3346)

'Buyers only' = based on intakes of rice-buying households only, when bought rice is fortified with WFP mid-point values (women *n*=3007; children *n*=1882).

Figure 3. Probability of micronutrient adequacy of pregnant women, their mothers-in-law and male household head in Nepal Province 2, with and without rice fortification

From Low Birth Weight South Asia Trial data.

'Current' = based on unfortified diets of all respondents (n=128);

'Full sample' = based on intakes of all respondents when bought rice is fortified with WFP mid-point values (n=128);

Buyers only = based on intakes of rice-buying households only, when bought rice is fortified with WFP mid-point values (n=97).

Figure 4. Comparison of the difference in probability of adequacy with and without fortification, between pregnant women and male household heads

Values given above the bars for women represent the difference between pregnant women's and men's increase in probability of adequacy after fortification of rice.

p values for tests of differences in the increase in PA between pregnant women and men are provided below each nutrient name, where * p<0.05, ** p<0.01, *** p<0.001

Table 1. Micronutrient levels in unfortified uncooked rice and in dry weight of cooked rice from Bangladesh and USDA food composition estimates, and World Food Programme 2016, Bangladesh, and DePee fortificant specifications for fortified rice

Vit-amin	Parameters	Unit	Per 100 g of uncooked rice	Source of proposed FCT	Bangladesh estimates of composition of water-soluble B vitamins/ 100g dry weight converted from cooked rice[4]	USDA estimates of composition of water-soluble B vitamins/ 100g dry weight converted from cooked rice[4]	WFP standard for fortified rice[1]	Bangladesh* standard for fortified rice[2]	De Pee et al 2018 recommendation for fortified rice[3]
	Energy	Kcal	345	Nepal					
	Protein	g	6.8	Nepal					
	Calcium	mg	10	Nepal					
	Selenium	mcg	1.01	India					
	Zinc	mg	1.21	India			6.5	4.0	6.0
	Iron	mg	0.7	Nepal			4.5	6.0	4.0
A	Vitamin A	RE (mcg)	0	India			175	183	150
B_1	Thiamin	mg	0.21	Nepal	0.03 * 2.78 = 0.08	0.02 * 2.78= 0.06	0.75	0.5	0.5
B_2	Riboflavin	mg	0.06	Nepal	0.01 * 2.78= 0.03	0.01 * 2.78= 0.03			
B_3	Niacin	mg	1.9	Nepal	1.1 * 2.78= 3.06	0.04 * 2.78= 0.11	8.5	0	7.0

B_6	Pyridoxine	mg	0.12	India	0.03 * 2.78=	0.08	0.09 * 2.78=	0.25	0.9	0	0.6
B_9	Folate	mg	9.32	India	3 * 2.78=	8.34	3 * 2.78=	8.34	317	267	
	Folic Acid	mcg							190	160	130
B_{12}	Cobalamin	mcg	0	India	No info	No info	0	0	1.5	1.2	1.0
C	Ascorbic acid	mg	0	India							
E	alpha-tocopherol	mg	0.06	India							

FCT = Food Composition Table; WFP = UN World Food Programme

[1]WFP 2016 specification based on mid-point between minimum and maximum levels leaving factory

[2]Bangladesh estimates are for the household level after losses from storage.

[3]For population consuming 150 to 300 g/day [52]

[4]The conversion factor for weight of uncooked to cooked rice is 0.36 making the conversion from cooked rice to dry rice 1/36 = 0.278.

Table 2. Socio-demographic and health characteristics of LBWSAT and national Annual Household Survey III samples

	National annual household survey[1]		LBWSAT		
	n	Median, mean, or %		***n***	Median or %
Age					
Women aged 15-49 years, median [25th, 75th centiles]	5443	28 [21, 36]	Pregnant women, median [25th, 75th centiles]	150	21 [19, 24]
			Mothers-in-law, median [25th, 75th centiles]	150	50 [44, 56]
Children aged 5-12 years, median [25th, 75th centiles]	3,346	9 [7, 11]	Male household heads, median [25th, 75th centiles]	150	39 [25, 56]
Caste group				150	
			Dalit and Muslim (disadvantaged groups),		35.3%
			Janjati / other *Terai* castes		42.7%
			High caste (*Yadav*, *Brahmin*)		22.0%
Maternal education				150	
Ability to read (%)	4360	49.6%	Never went to school		56.1%
Education grade (mean ± SE)	4360	3.4 ± 0.2	Primary to lower secondary		27.0%

			Secondary and above		16.9%
Male education				147	
Ability to read (%)	4360	68.6%	Never went to school		42.2%
Education grade (mean ± SE)	4360	5.0 ± 0.1	Primary to lower secondary		29.9%
			Secondary and above		27.9%
Overseas migration				128	
			Any household member living overseas		46.1%
Household Food Insecurity Access Scale				134	
			Any food insecurity in the past 4 weeks		30.6%
Minimum dietary diversity (>=5 out of 10 food groups)				150	
			Pregnant women		58.0%
			Mothers-in-law		59.3%
			Male household heads		62.0%
Low Mid-Upper Arm Circumference (<23cm)				150	
			Pregnant women		40.0%
			Mothers-in-law		35.3%
			Male household heads		14.0%

[1] Estimates after applying sampling weights

Table 3. Mean dietary nutrient intakes, with and without fortification of purchased rice, using WFP specifications

	National annual household survey		LBWSAT		
	Women 15-49y	Children 5-12y	Pregnant women	Mothers-in-law	Male household heads
n					
Current	5443	3346	128	128	128
Full sample	5443	3346	128	128	128
Buyers only	3007	1882	97	97	97
Mean ± SD intakes of nutrients not included in WFP rice premix					
Energy (kcal/d)					
Current	2060 ± 748	1,645 ± 632	2125 ± 729	2109 ± 781	2692 ± 765
Protein (g/d)					
Current	60.6 ± 24.9	47.2 ± 20.0	63.1 ± 24.0	62.8 ± 27.4	80.0 ± 25.5
Vitamin C (mg/d)					
Current	57.6 ± 49.7	41.3 ± 36.6	124.6 ± 152.6	130.8 ± 131.5	124.4 ± 100.6
Calcium (mg/d)					
Current	303 ± 234	236 ± 184	548 ± 422	448 ± 281	594 ± 417
Vitamin B_2 (riboflavin) (mg/d)					
Current	0.7 ± 0.4	0.6 ± 0.3	1.1 ± 0.6	1.0 ± 0.6	1.2 ± 0.6
Mean ± SD intakes of nutrients that are included in WFP rice premix					
Vitamin B_3 (niacin) (mg/d)					

Current	16.7 ± 7.2	13.1 ± 6.0	17.4 ± 6.3	17.8 ± 8.0	22.9 ± 7.7
Full sample	30.1 ± 18.2	24.6 ± 15.8	31.4 ± 14.3	31.4 ± 15.0	39.5 ± 16.0
Buyers only	42.7 ± 16.5	34.9 ± 14.9	35.6 ± 13.8	35.5 ± 14.5	44.4 ± 14.6
Vitamin B_6 (pyridoxine) (mg/d)					
Current	2.2 ± 0.9	1.7 ± 0.7	2.2 ± 0.9	2.2 ± 0.9	2.8 ± 0.9
Full sample	3.6 ± 2	2.9 ± 1.7	3.7 ± 1.7	3.7 ± 1.6	4.5 ± 1.8
Buyers only	4.9 ± 1.9	4.0 ± 1.7	4.2 ± 1.7	4.1 ± 1.6	5.1 ± 1.7
Vitamin A (RE/d)[1, 2]					
Current	328 ± 487	242 ± 359	477 ± 444	531 ± 687	504 ± 411
Full sample	603 ± 568	480 ± 437	766 ± 520	812 ± 766	845 ± 483
Buyers only	836 ± 512	658 ± 407	849 ± 545	887 ± 830	917 ± 480
Vitamin B_1 (thiamin) (mg/d) [1]					
Current	1.7 ± 0.7	1.3 ± 0.6	1.8 ± 0.7	1.8 ± 0.8	2.3 ± 0.9
Full sample	2.9 ± 1.6	2.3 ± 1.4	3.1 ± 1.3	3.0 ± 1.4	3.8 ± 1.5
Buyers only	3.9 ± 1.5	3.2 ± 1.4	3.4 ± 1.3	3.4 ± 1.3	4.2 ± 1.4
Vitamin B_9 (folate) (µg/d)[1]					
Current	265 ± 167	200 ± 121	326 ± 163	341 ± 170	390 ± 153

Full sample	763 ± 616	630 ± 527	851 ± 471	850 ± 459	1010 ± 498
Buyers only	1240 ± 522	1,013 ± 459	1013 ± 422	1000 ± 415	1183 ± 432
Vitamin B_{12} (µg/d)[1]					
Current	0.5 ± 0.6	0.4 ± 0.4	0.7 ± 0.8	0.6 ± 2.3	0.7 ± 1.1
Full sample	2.8 ± 2.8	2.4 ± 2.4	3.2 ± 2.2	3.0 ± 3.3	3.7 ± 2.5
Buyers only	5.1 ± 2.3	4.2 ± 2.0	3.9 ± 2.0	3.9 ± 3.4	4.6 ± 2.1
Iron (mg/d)[1]					
Current	11.7 ± 5.4	9.2 ± 4.4	15.0 ± 5.6	15.3 ± 7.3	19.6 ± 6.5
Full sample	18.8 ± 10.2	15.3 ± 8.7	22.4 ± 8.8	22.5 ± 10.2	28.4 ± 9.6
Buyers only	25.3 ± 9.5	20.7 ± 8.3	24.5 ± 8.7	24.7 ± 10.1	30.9 ± 9.2
Zinc (mg/d)[1]					
Current	9.5 ± 3.9	7.5 ± 3.2	10.0 ± 3.6	10.0 ± 4.5	12.8 ± 4.3
Full sample	19.7 ± 13.1	16.3 ± 11.4	20.8 ± 10.2	20.5 ± 10.5	25.5 ± 11.4
Buyers only	29.4 ± 11.6	24.1 ± 10.5	24.0 ± 9.6	23.7 ± 9.8	29.4 ± 10.1

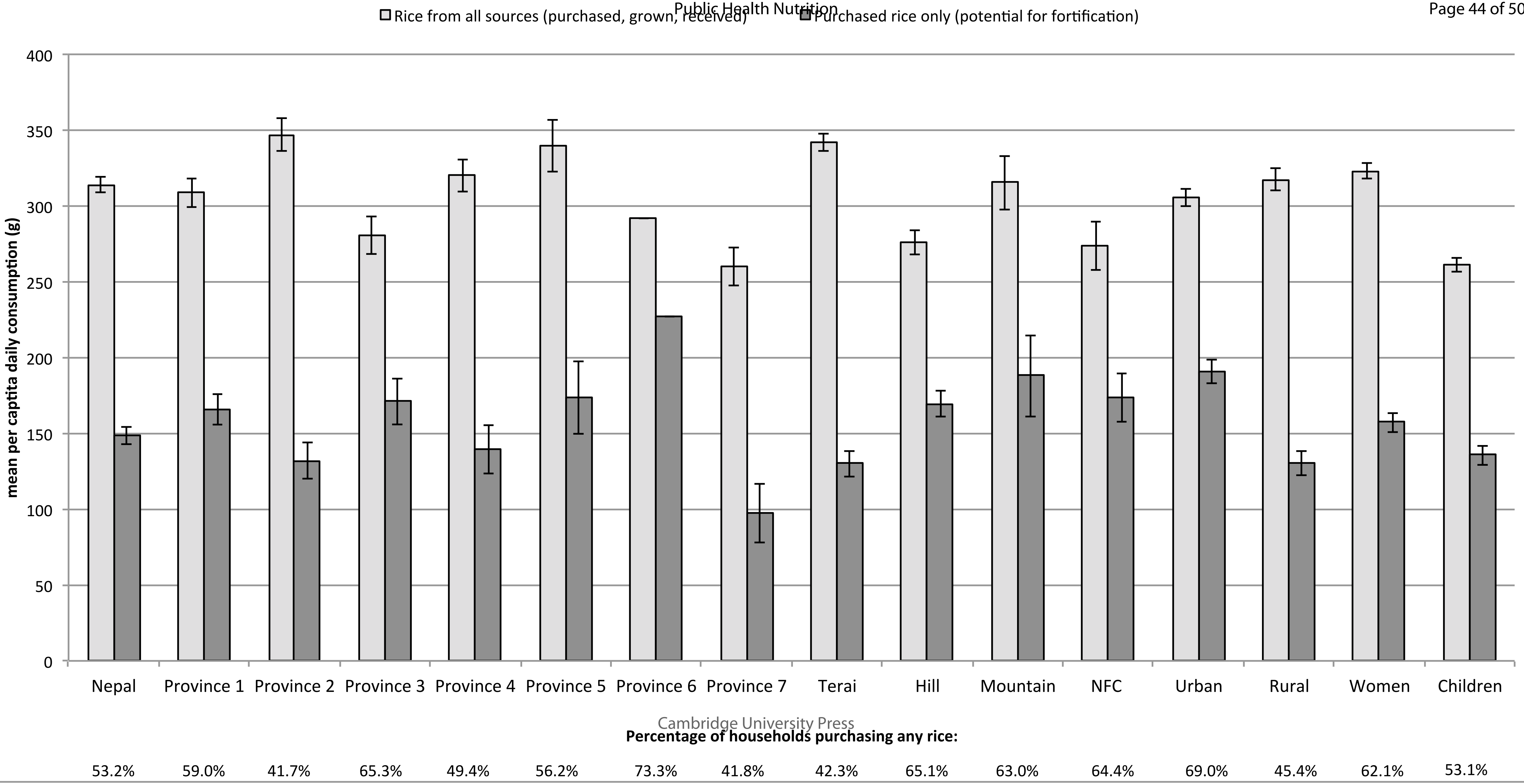
Current = current intakes of total population with no fortification;
Full sample = intakes of total population when bought rice is fortified with WFP median values;
Buyers only = intakes of rice-buying households only, when bought rice is fortified.
[1] Nutrient is also fortified in Bangladeshi rice premix, as reported in Supplemental Table 2.
[2] Vitamin A intakes excluding mango are: pregnant women 334 ± 312 RE/d; mothers-in-law 360 ± 644 RE/d; male household heads 353 ± 336 RE/d

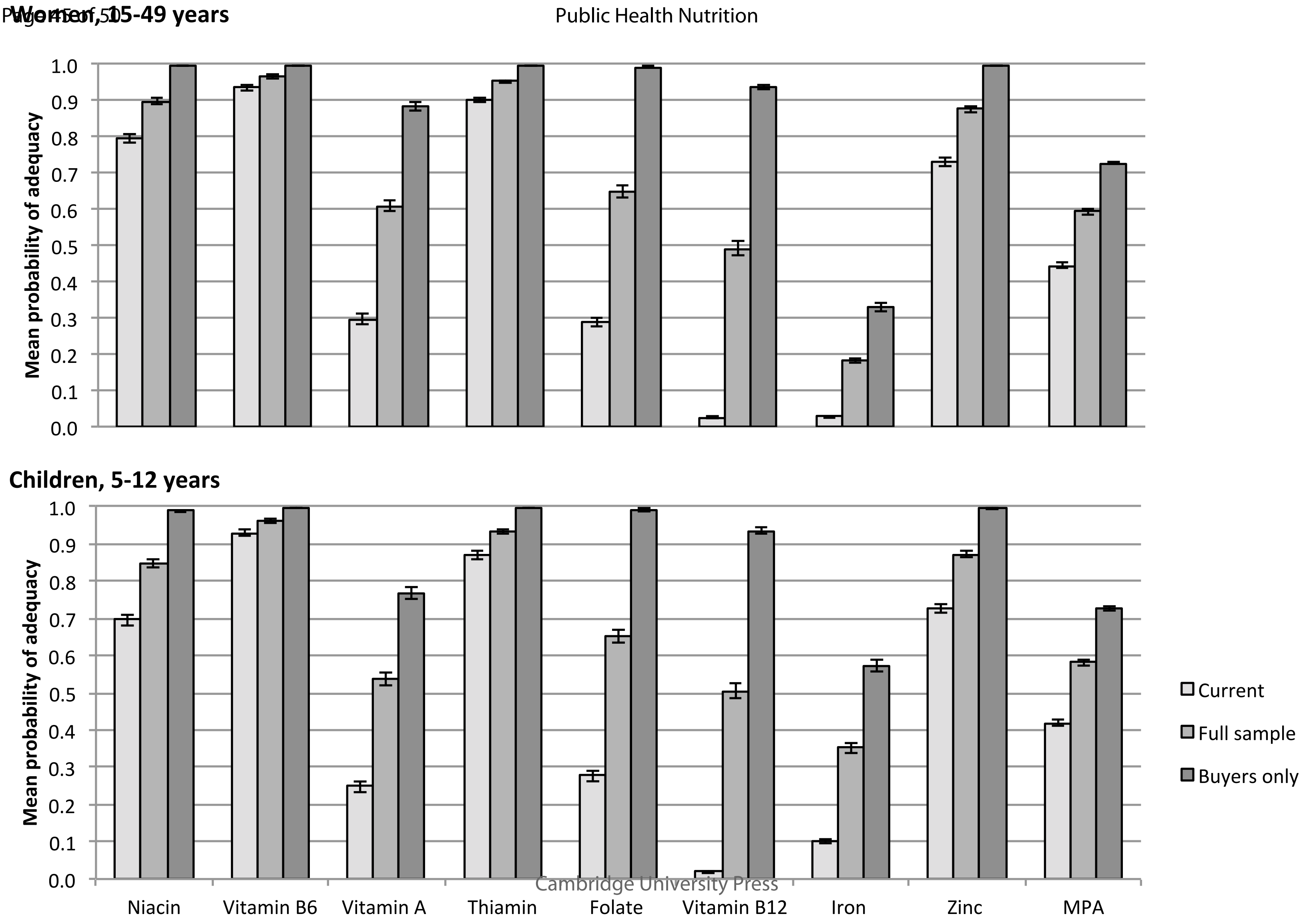
Table 4. Regional comparisons of the difference in women's mean probability of adequacy, with and without fortification[1]

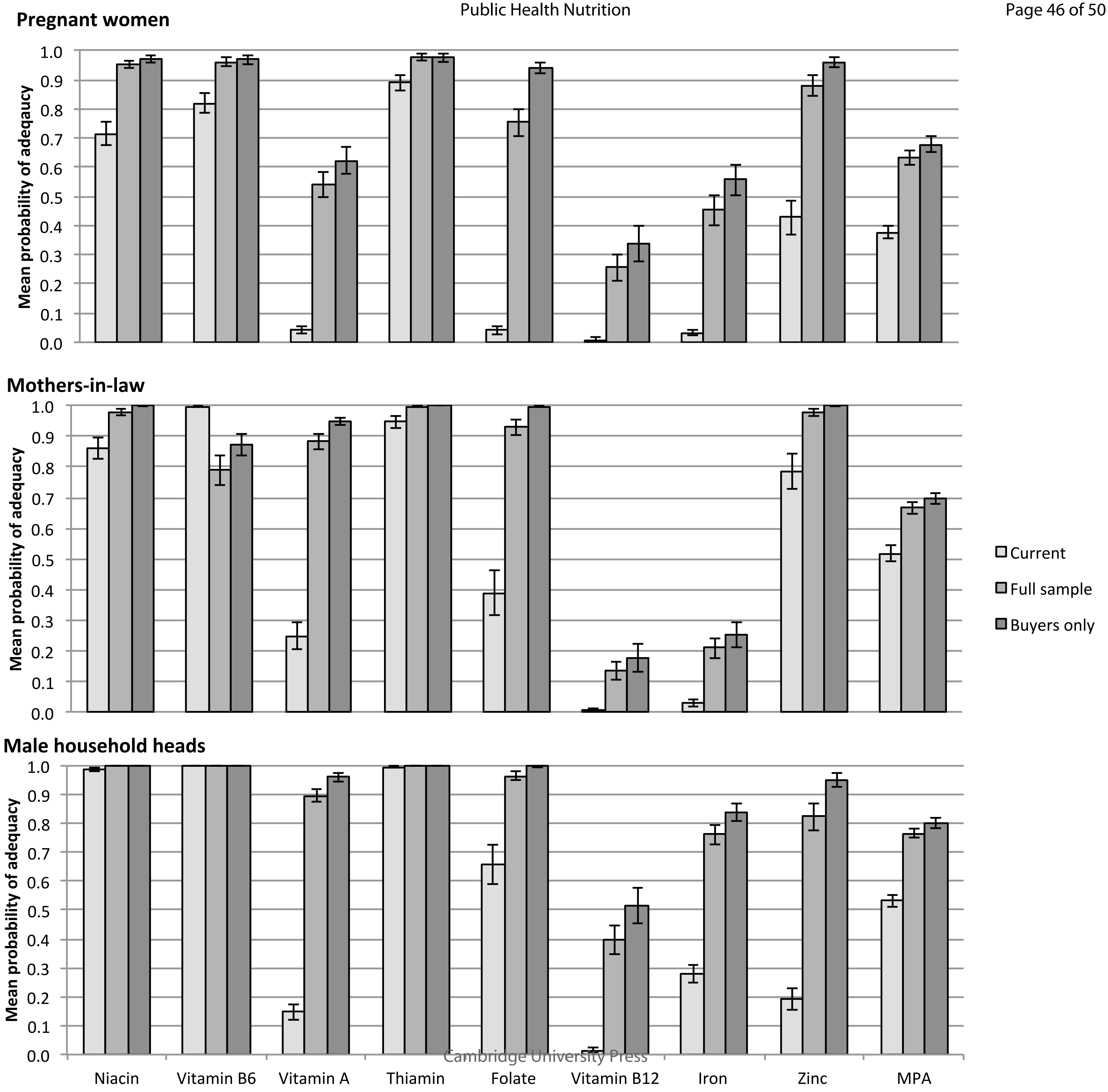
	Mean ± SD	Conditional mean estimates (95% CI)	*p*-value
Federal State of Nepal			
Province 3	0.17 ± 0.16	Ref	
Province 1	0.17 ± 0.18	0.00 (-0.05, 0.05)	0.977
Province 2	0.11 ± 0.15	-0.06 (-0.11, -0.01)	0.013
Province 4	0.13 ± 0.15	-0.04 (-0.09, 0.00)	0.077
Province 5	0.15 ± 0.15	-0.02 (-0.09, 0.05)	0.575
Province 6	0.21 ± 0.15	0.04 (0.00, 0.07)	0.068
Province 7	0.12 ± 0.17	-0.05 (-0.12, 0.02)	0.127
Ecological Zone			
Terai	0.11 ± 0.15	Ref	
Hill	0.19 ± 0.17	0.08 (0.05, 0.10)	<0.001
Mountain	0.19 ± 0.16	0.07 (0.01, 0.14)	0.019
Social Safety Net areas			
Non NFC	0.14 ± 0.16	Ref	
NFC district	0.20 ± 0.17	0.05 (0.01, 0.10)	0.012
Rural/Urban			

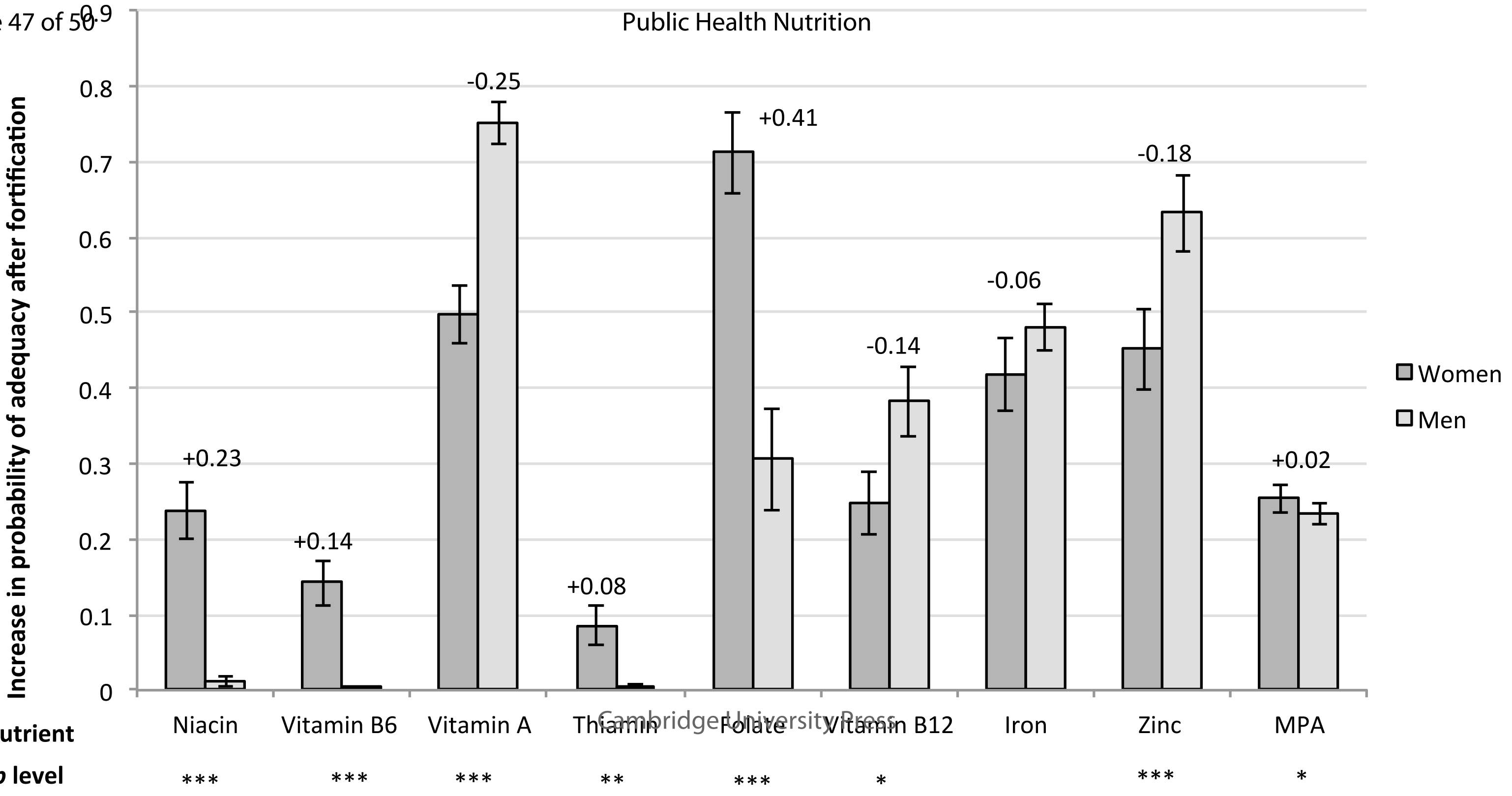
Urban	0.18 ± 0.19	Ref	
Rural	0.13 ± 0.15	-0.05 (-0.09, -0.01)	0.011

[1] *n*=5443


Rice from all sources (purchased, grown, received)
Purchased rice only (potential for fortification)
mean per captita daily consumption (g)
0
50
100
150
200
250
300
350
400
Nepal
Province 1
Province 2
Province 3
Province 4
Province 5
Province 6
Province 7
Terai
Hill
Mountain
NFC
Urban
Rural
Women
Children
Percentage of households purchasing any rice:
53.2%
59.0%
41.7%
65.3%
49.4%
56.2%
73.3%
41.8%
42.3%
65.1%
63.0%
64.4%
69.0%
45.4%
62.1%
53.1%


Women, 15-49 years
Mean probability of adequacy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Children, 5-12 years
Mean probability of adequacy
Niacin
Vitamin B6
Vitamin A
Thiamin
Folate
Vitamin B12
Iron
Zinc
MPA
Current
Full sample
Buyers only


Pregnant women
Mothers-in-law
Male household heads
Mean probability of adequacy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Niacin
Vitamin B6
Vitamin A
Thiamin
Folate
Vitamin B12
Iron
Zinc
MPA
Current
Full sample
Buyers only


Increase in probability of adequacy after fortification
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
+0.23
+0.14
-0.25
+0.08
+0.41
-0.14
-0.06
-0.18
+0.02
Women
Men
Nutrient
Niacin
Vitamin B6
Vitamin A
Thiamin
Folate
Vitamin B12
Iron
Zinc
MPA
p level
***
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Supplementary data

Supplemental Table 1. Daily frequency of consumption of rice dishes, other staple foods, and other common foods from LBWSAT sample[1]

	Frequency of intakes per day ± SD			
	Pregnant women	**Mothers-in-law**	**Household heads**	**Average**
Dishes made with polished white rice				
Boiled white rice	2.03 ± 0.60	1.74 ± 0.54	1.72 ± 0.67	1.83 ± 0.62
Fried rice	0.01 ± 0.05	0.01 ± 0.05	0.00 ± 0.04	0.01 ± 0.04
Rice pudding (*kir*)	0.03 ± 0.12	0.05 ± 0.14	0.02 ± 0.08	0.03 ± 0.11
Rice gruel (*jaulo*) or rice mixture (*khichadi*) made with dal and sometimes vegetables (*khichadi*)	0.03 ± 0.14	0.04 ± 0.20	0.04 ± 0.19	0.04 ± 0.18
Other rice-based foods				
Puffed rice	0.10 ± 0.24	0.09 ± 0.21	0.14 ± 0.31	0.11 ± 0.26
Beaten rice	0.08 ± 0.20	0.05 ± 0.14	0.16 ± 0.29	0.10 ± 0.22
Rice flour-based snacks, including *sel roti*, *malpuwa* and *bagiya*	0.04 ± 0.13	0.04 ± 0.16	0.04 ± 0.15	0.04 ± 0.15
Other starchy staples				
Fresh corn - on the cob or roasted	0.02 ± 0.12	0.01 ± 0.09	0.01 ± 0.09	0.01 ± 0.10
Breads, including flatbreads without oil *roti*, flatbreads made with oil (*puri*, *paratha*, *naan*) and risen bread (*pau roti*)	1.03 ± 0.59	0.95 ± 0.58	0.99 ±0.64	0.99 ± 0.61
Stiff porridge made with flour (various types of staples), oil, and sugar (*haluwa*)	0.04 ± 0.12	0.04 ± 0.12	0.04 ± 0.13	0.04 ± 0.12
Starchy fried and/or sweet snacks	0.16 ± 0.38	0.15 ± 0.33	0.18 ± 0.40	0.16 ± 0.37
Tubers - boiled, fried, in curry or in chutney	0.52 ± 0.51	0.42 ± 0.48	0.43 ± 0.45	0.46 ± 0.48
Other common foods				

Supplementary data

	Frequency of intakes per day ± SD			
	Pregnant women	**Mothers-in-law**	**Household heads**	**Average**
Spiced lentil soup - *dal*	1.06 ± 0.64	0.90 ± 0.55	0.92 ± 0.55	0.96 ± 0.59
Tea with sugar and milk	0.16 ± 0.37	0.30 ± 0.54	0.49 ± 0.64	0.32 ± 0.54
Pointed gourd curry	0.41 ± 0.56	0.37 ± 0.53	0.39 ± 0.50	0.39 ± 0.53
Mango [2]	0.30 ± 0.48	0.33 ± 0.45	0.28 ± 0.41	0.30 ± 0.45
Buffalo milk	0.28 ± 0.43	0.10 ±0.23	0.21 ± 0.45	0.19 ± 0.39

LBWSAT = Low Birth Weight South Asia Trial
[1] *n*=150
[2] Data were collected during June – September. Peak mango season is June to July.

Supplementary data

Supplemental Table 2. Mean dietary intakes of micronutrients that are included in Bangladesh rice premix, after fortification of purchased rice using Bangladesh standards

	National annual household survey		LBWSAT		
	Women 15-49y	Children 5-12y	Pregnant women	Mothers-in-law	Male household heads
Sample size	***n***	***n***	***n***	***n***	***n***
Full sample	5443	3346	128	128	128
Buyers only	3007	1882	97	97	97
Nutrient intakes	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Vitamin A (RE/d)					
Full sample	615 ± 576	490 ± 444	779 ± 525	824 ± 771	860 ± 489
Buyers only	859 ± 537	677 ± 413	865 ± 549	903 ± 834	936 ± 485
Vitamin B_1 (thiamin) (mg/d)					
Full sample	2.5 ± 1.2	2.0 ± 1.1	2.6 ± 1.0	2.6 ± 1.1	3.3 ± 1.2
Buyers only	3.2 ± 1.3	2.6 ± 1.1	2.9 ± 1.1	2.9 ± 1.1	3.6 ± 1.2
Vitamin B_9 (folate) (µg/d)					
Full sample	685 ± 528	562 ± 450	768 ± 409	770 ± 400	912 ± 426
Buyers only	1086 ± 454	885 ± 396	904 ± 373	894 ± 367	1056 ± 374
Vitamin B_{12} (µg/d)					
Full sample	2.4 ± 2.4	2.0 ± 2.0	2.7 ± 1.9	2.6 ± 3.1	3.1 ± 2.1
Buyers only	4.2 ± 2.0	3.5 ± 1.7	3.3 ± 1.7	3.3 ± 3.2	3.9 ± 1.8
Iron (mg/d)					
Full sample	21.1 ± 12.7	17.4 ± 10.9	24.9 ± 10.4	24.9 ± 11.6	31.3 ± 11.4
Buyers only	29.9 ± 11.8	24.5 ± 10.1	27.7 ± 10.1	27.9 ± 11.3	34.7 ± 10.5
Zinc (mg/d)					
Full sample	15.8 ± 8.8	13.0 ± 7.7	16.7 ± 7.2	16.5 ± 7.7	20.6 ± 8.0
Buyers only	21.7 ± 8.6	17.8 ± 7.4	18.6 ± 7.1	18.5 ± 7.5	23.0 ± 7.3

'Full sample' = intakes of total population when bought rice is fortified with Bangladesh premix (mid-values of household fortificant levels rather than factory levels);
'Buyers only' = intakes of rice-buying households only, when bought rice is fortified with Bangladesh premix (mid-values of household fortificant levels rather than factory levels).

Supplementary data

Supplemental Table 3. Agreement between observed and predicted daily energy (kcal) intakes from LBWSAT data

	Pregnant women[1]		Mothers-in-law[1]		Male household head[1]	
Assumptions used in calculation of adult male equivalents	Mean difference (95% CI)	LOA	Mean difference (95% CI)	LOA	Mean difference (95% CI)	LOA
Moderate PAL, no adjustment for pregnancy	-84 (-155 to -13)	-968 to 800	18 (-43 to 80)	-748 to 785	66 (-15 to 146)	-936 to 1067
Moderate PAL, with adjustment for pregnancy	-311 (-384 to -238)	0 to 592	119 (56 to 182)	-661 to 899	192 (112 to 273)	-805 to 1189
Self-reported PAL[2] and weight (kg), no adjustment for pregnancy	-8 (-77 to 62)	-866 to 851	-33 (-95 to 29)	-804 to 738	41 (-39 to 120)	-939 to 1021
Self-reported PAL[2] and weight (kg), adjustment for pregnancy	-240 (-311 to -170)	0 to 629	71 (8 to 134)	-704 to 846	169 (91 to 248)	-803 to 1141

LOA = Limits of agreement, calculated as the mean difference ± 1·96 SD; PAL = Physical Activity Levels.
[1] n=150
[2] Based on self-reported activity levels from 24-h recall period, categorised as sedentary (PAL=1.6); moderate (PAL=1.9); strenuous (PAL=2.2).