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Reducing gender bias in household consumption data: Implications for food fortification policy

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ABSTRACT

Household Consumption Expenditure Survey (HCES) data are increasingly used to inform nutrition policy around the world, most prominently for food fortification programs. However, they risk providing incorrect and gender-biased estimates of dietary intakes. We use both 7-day HCES and 24-hour dietary recall (24HR) data on all members of 5604 households in rural Bangladesh to disentangle the two main sources of error: 1) mismeasurement of household consumption, and 2) intra-household allocation assumptions used to individualize household consumption. We show that, relative to 24HR, HCES overestimate household-level quantities and underestimate women's share of household foods. Errors from modeling the potential benefits and risks of fortification depend on the food – better measurement is needed for foods consumed episodically (e.g. wheat flour or sugar) or in small quantities (e.g. salt and oil). Beyond mean bias, we find poor and heteroskedastic agreement between HCES and 24HR methods, which is more driven by mismeasurement of food quantities than the application of flawed assumptions about food allocation – at least in the Bangladeshi context. We demonstrate a novel generalizable method for improving HCES intake estimates by drawing on the advantages of both HCES and 24HR data. Using a small sample of 24HR data to generate context- and food-specific quantity and allocation corrections, we can almost eliminate mean bias. With further validation, we hope our proposed method can be used to ensure that HCES estimates account for locally-specific measurement error and gender norms, and that nutrition policy based on these data will be safer and more gender-sensitive.

1. Introduction

Household Consumption and Expenditure Surveys (HCES) are increasingly being used to inform nutrition policy around the world, most prominently for food fortification programs. Food fortification, which is emerging as a dominant strategy to address micronutrient deficiencies (Dary and Hurrell, 2006; Das et al., 2019; Muthayya et al., 2012; Peña-Rosas et al., 2019), relies on high-quality national food consumption data to estimate micronutrient gaps, identify fortifiable foods, and set standards for what level of nutrients to fortify them with (Global Alliance for Improved Nutrition, 2017). It is well-known that the benefits of using HCES to inform nutritional programming – including their low cost and nationally-representative sampling frames – must be weighed against their lack of information on, for example, meal partakers, food waste, food purchased outside the home, and their measurement error in quantity estimation (Smith and Subandoro, 2007).

A major concern is that household consumption surveys do not measure individual food intakes, and analysis therefore relies on an assumption of how households allocate food to their members (Coates et al., 2017). The most common approach is to assume that foods are allocated according to individuals' biological energy requirements (Dary and Imhoff-Kunsch, 2010) – an assumption that has limited basis in behavioral science (Harris-Fry et al., 2017; Miller, 1997). This is often done by applying 'Adult Male Equivalent' (AME) weights to estimates of household-level consumption, where adult men have a weight of 1 and other members are given weights corresponding to their proportion of an adult male's energy requirements. If households' actual food allocation practices vary from this energy needs distribution rule, fortification programs that rely solely on HCES data are at risk of setting

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harmful fortification standards that either do not meet nutritional needs for household members who eat less than their estimated quantities, or exceed upper limits for those who consume more. Using household-level data to monitor and evaluate the nutritional impact of large-scale food fortification likewise runs the risk of neglecting heterogeneous effects on demographic subgroups, including nutritionally vulnerable adolescent girls and pregnant women. Analyses from Nepal, Malawi, and Bangladesh have shown differential potential effects of food fortification by gender, geography, and wealth status (Raghavan et al., 2019; Saville et al., 2020; Tang et al., 2021), highlighting the need for accurate equity analyses.

Recognizing the well-documented gender inequalities that persist in many parts of the world, researchers using HCES data often caveat their results by noting the possibility that women receive less than their energy requirements, and the corresponding risk of overestimating their potential benefits of fortification. However, empirical evidence reveals substantial cross-country variation in the gender bias in intrahousehold allocation of dietary energy (Berti, 2012), implying that blanket assumptions should be avoided. There are few studies on the allocation of micronutrients and non-staple (but potentially fortifiable) foods. Those that exist generally show larger inequalities in intra-household allocation macronutrients and staple foods than micronutrients (Rahman, 2013; Harris-Fry et al., 2021; Coates et al., 2018), and vast heterogeneity within and between contexts (Harris-Fry et al., 2017). This implies that staple food fortification could be a particularly beneficial intervention for women, who have comparatively lower micronutrient adequacy but receive larger shares of fortifiable staple foods such as flour and rice (Zamora and De-Regil, 2014). In other words, food fortification may provide a 'gender intentional' but not 'gender transformative' intervention, that closes gender gaps in micronutrient deficiencies but does so without challenging the patriarchal status quo (Bill and Melinda Gates Foundation, 2020).

A small body of research has compared HCES estimates of individual consumption using an Adult Male Equivalent (AME) allocation rule, with estimates from the most common individual-level dietary assessment method: 24-hour dietary recall (Bromage et al., 2018; Dary and Jariseta, 2012; Engle-Stone and Brown, 2015; Sekula et al., 2005). In two sub-Saharan African contexts, household survey-based data generated lower estimates of consumption of potentially fortifiable foods compared with 24-hour recall (24HR) data. Dary and Jariseta (2012) estimated the consumption profile of vegetable oil, sugar, wheat flour, maize flour, and rice in Uganda. They found that, while HCES data identified a larger number of households using fortifiable foods than the 24-hour recall, the 24-hour recall method computed higher intake values of almost all five foods, perhaps because the week's consumption is not equally divided across all days of the week. Engle-Stone and Brown (2015) compared results from the HCES of the Third Cameroon Household Survey with the results of a national dietary survey which included both a food frequency questionnaire and a 24HR recall. They found that household survey-based estimates of most fortifiable food consumption were consistently lower compared to 24-hour recall, again likely reflecting the HCES smoothing of episodically consumed foods.

1.1. Bangladesh: A case study

Bangladesh offers a particularly unique opportunity to evaluate the validity of using household survey data to measure intake of fortifiable foods, and to find ways to improve HCES estimates. The Bangladesh Integrated Household Survey (BIHS), which has been carried out over three rounds between 2011 and 2019, is one of very few nationally representative datasets to include measures of both household food consumption and individual dietary intake from the same sample. Unlike in sub-Saharan Africa, analyses of the BIHS data show that HCES predictions over-estimate consumption. Drawing on the earliest round of BIHS data, Coates et al. (2017) found that AME-based predictions of nutrient intake were on average within ten percentage points of individually reported intakes, but with wide error margins and with around 20% of adults being misclassified according to their dietary energy adequacy status. Predictions were less accurate for infants and children than for other demographic groups, likely due in part to a lack of information on breastfeeding. The AME prediction also overestimated the iron and animal-source protein intake of adult women, by 8 and 11 percentage points respectively. Karageorgou et al. (2018) evaluation of the 2011–2012 BIHS showed that mean individualized household estimates significantly exceeded individual intakes for nearly all dietary factors assessed, including by 12% for total energy, 0–242% for major food groups, 11–30% for macronutrients and 13–55% for micronutrients. The degree of overestimation varied by both gender and estimation method.

An alternative analysis of the second round of the 2011–2012 BIHS relied exclusively on quantities from the 24-hour intake estimates, but compared actual individual consumption to AME-based allocations of the household sum of the 24-hour intakes (Sununtnasuk and Fiedler, 2017). This analysis therefore eliminates any bias introduced by measurement error (such as portion sizes or forgotten foods) and exclusively describes the age and gender bias introduced by applying AMEs. They found that the two methods generally agreed on the classification of individuals having (in)adequate nutrient intakes, suggesting that the use of AMEs may be suitable in this context. For iron, vitamin A, and calcium, >97% of all individuals had the same classification of adequate or inadequate nutrient intakes using 24HR and AME-based estimates, and for energy and zinc, 77% and 83% of the sample population were identically classified, respectively.

1.2. Contribution of this study

This paper aims to provide constructive solutions for how we can use HCES data to identify foods to fortify and accurately model the coverage and potential effects of fortification on micronutrient deficiencies and excess in men and women – in the absence of large-scale, nationally representative data on intra-household food allocation, which are often cost prohibitive (Fiedler, 2013). To do this, we use HCES and 24-hour dietary recall (24HR) data from BIHS (2018–19) to estimate coverage and consumption of five fortifiable foods of different types: foods that are consumed in small quantities (salt and oil), episodically (wheat flour and sugar), and regularly and in large quantities (rice).

First, in contrast to previous studies that have simply characterized bias in HCES estimates, we use new methods to identify and decompose sources of bias in coverage and intake of fortifiable foods. We show that, relative to 24HR, HCES overestimate household-level *quantities* but underestimate women's *share* of household foods. Errors from modeling the potential benefits and risks of fortification depend on the food – better measurement is needed for foods consumed episodically (e.g. wheat flour or sugar) or in small quantities (e.g. salt and oil), and measurement of foods eaten outside of the home should be included.

Second, we look beyond mean bias to reveal poor and heteroskedastic agreement between HCES and 24HR methods, which is primarily driven by mismeasurement of food quantities – more so than the application of flawed assumptions about the intra-household allocation of food. This seems to be because HCES consistently overestimate food consumption, whereas intra-household allocation of food is highly variable. This again suggests that HCES-derived dietary estimates could be substantially improved by refining quantification methods, ideally by including nutritionists in survey design and utilizing novel methods that are being developed in nutritional sciences.

Third, although these conclusions may be limited to the Bangladeshi context, we demonstrate the application of a novel method that can improve HCES estimates in any context. Our proposed method adjusts household-level quantities by generating a "local" food-specific allocation rule from a small sample of 24HR data, and applying these inductively calculated weights to the household data. We thus test whether using locally- and food-specific allocation rules – which may be influenced by cultural norms, food scarcity, and gender norms – improves estimates of individual food and nutrient intakes. This method almost eliminates bias in intakes of commonly consumed foods, though does not resolve poor and heteroskedastic agreement between HCES and 24HR. With further testing in other contexts and age groups, we hope our proposed method will be used to ensure that HCES estimates account for locally-specific measurement error and gender norms, and that food fortification and other nutrition interventions based on these data will be safer and more gender-intentional.

2. Methods

2.1. Study context

Bangladesh faces a high nutritional 'triple burden' of underweight (20% men; 10% women), overweight and obesity (18% men; 32% women), and micronutrient deficiencies (40% anemia in women) (NIPORT and ICF, 2020). Underweight has declined rapidly over the past few decades, but micronutrient deficiencies remain a serious public health concern. Intakes of vitamin A, riboflavin, folate, vitamin B_{12} and calcium are particularly inadequate (=<3 % of women's intakes are adequate) (Arsenault et al., 2013). In many parts of Bangladesh there are high levels of iron contamination in the groundwater, so, unlike many other countries, the high burden of anemia is not predominantly attributable to iron deficiency (Ahmed et al., 2018; Merrill et al., 2011). Anemia in Bangladesh is likely also driven by deficiencies in multiple other micronutrients, as well as non-dietary factors such as infection and haemoglobinopathies.

Co-occurring in the same communities, and even within the same individuals, is a high prevalence of diabetes and hypertension (Fottrell et al., 2018). Together, this health profile reflects the nutritional transition towards more sedentary lifestyles, along with an increased availability of cheap calories and 'junk foods' (Nujhat et al., 2020). Diets are characterized by low consumption of fruits and vegetables; some consumption of fish, but limited consumption of other animal-source foods like meat, eggs and dairy; high consumption of staple foods (predominantly rice); and rising consumption of fats, oils, salt, and sugars (Harris-Fry et al., 2015).

Qualitative evidence of gender bias in food allocation in Bangladesh lends further support to the concern that household-based measures may not capture individual nutritional vulnerabilities. Prevalent gender norms dictate that women receive small meal portions and sacrifice their food consumption so that male family members can eat more (Blum et al., 2019; Lentz, 2018; Levay et al., 2013). A study of low-income households found that food insecurity and prevailing gender norms interact to limit dietary intake. So, in food insecure environments, gender inequities in food distribution result in adolescent girls being given inadequate food to meet their nutritional needs (Blum et al., 2019). Other research in rural Bangladesh has documented women limiting their consumption of food or eating less nutritious foods in an attempt to avoid domestic violence (Lentz, 2018).

Food fortification could contribute to current efforts to reduce micronutrient deficiencies in Bangladesh, and potentially close gender gaps in nutritional inequities. Currently, free provision of iron and folic acid supplements is part of routine antenatal care in Bangladesh, although compliance is reportedly low (NIPORT and ICF, 2020). Vitamin A supplements are provided to children aged 12–59 months every 6 months, with relatively high coverage (79%) (NIPORT and ICF, 2020). Bangladesh has been fortifying salt with iodine since 1989, with an estimated 69% of salt iodized (National Micronutrient Survey, 2011–12), and since 2013 the government has mandated vitamin A fortification of edible oils, with an estimated 61% of oils being fortified (GAIN, 2016). Wheat flour and rice fall under 'voluntary fortification' so only 1–2% are fortified, but fortification of rice in social safety nets has shown promising results (Ebbing et al., 2015) and wheat fortification is being actively assessed (Food Fortification Initiative 2020). Sugar is not currently fortified in Bangladesh. Reliable information is needed to estimate the potential for food fortification to improve micronutrient adequacy without risk of excess, and consider the equity implications of these interventions.

2.2. Sampling and field procedures

We use the 2018–19 BIHS, which is the third round of the BIHS conducted by International Food Policy Research Institute (IFPRI). The survey used a two-stage sampling design, covering 5604 households containing a sample of 23,121 household members and 14,097 adults (56% women). Households were sampled from 325 primary sampling units (PSU) across eight strata. The sample is representative of rural Bangladesh and seven administrative divisions of the country: Barisal, Chittagong, Dhaka, Khulna, Rajshahi, Rangpur, and Sylhet. Data were collected from Nov 2018 to Apr 2019, to exclude Bangladesh's biannual *manga*, or lean seasons, that take place during crop planting.

This sampling frame has two implications for our analyses. First, research from various countries shows that urban populations, particularly urban men, are most at risk of exceeding upper-level micronutrient limits from fortified foods due to higher consumption rates of industrially processed foods, so we may underestimate risk of exceeding upper tolerable levels in urban areas (Engle-Stone et al., 2019). Second, our results may overestimate household food allocation ratios because studies from Bangladesh have shown more gender inequality in food-scarce conditions (e.g. Abdullah and Wheeler (1985); Blum et al., (2019)).

We use BIHS data on key economic and demographic characteristics; dietary intakes of all household members using a single 24-hour dietary recall (24HR) and weighing method; and household expenditure and consumption (HCES) data. For the HCES module, the main female respondent answered whether the household consumed any of almost 300 commonly consumed food items over the previous seven days, the total quantity consumed, and information about the source (purchased or produced) and the cost of each food item. Unlike the 24-hour dietary recall, the HCES did not collect data on meals eaten or prepared outside of the home, food given to guests or animals, or food waste. However, (unlike 24HR data) HCES data do contain information on where food was acquired, so we can distinguish between home-produced (not industrially fortifiable) versus purchased (fortifiable) ingredients.

The 24HR data contains information on the individual prepared weight of each food item eaten over a 24-hour period, as well as household-level recipe ingredients and their corresponding raw weights. The main cook in the household was responsible for providing information on recipes and portion sizes. The 24HR data contain information on the food's source (i.e., home-cooked, purchased, or eaten at work), but do not collect information on the source of home-cooked ingredients. So, we have information of foods consumed outside of the home but cannot determine if ingredients were home produced or purchased (and therefore industrially fortifiable).

The BIHS 24HR data contains a single day of measurement, without any duplicates. Given the known day-to-day variation in dietary intakes, this means that the 24HR intake distributions are wider than would be observed with 'usual' intakes (Dodd et al., 2006) (although, with the exception of wheat flour, they are not wider than intake estimates derived from the HCES 7-day recall in BIHS). As a result, mean 24HR estimates of *ubiquitously* consumed foods and nutrients should reflect the 'true' intake mean[1], and, given their more detailed and individualized measurement methods, we can reasonably use them to draw conclusions about mean biases in quantity estimates from HCES data. On the other hand, for *episodically* consumed foods, we use 24HR data to identify gender biases that HCES data would have missed but recognize that HCES estimates may provide a closer measure of usual intakes, because

[1] In the absence of systematic measurement error.

they smooth weekly consumption (as we would do in our analyses, if we had multiple 24HR measures per person (Kipnis et al., 2009)). Additionally, due to the inflated variance of the single day 24HR, we cannot claim disagreement between measures is solely attributable to measurement error in HCES data.

2.3. Estimating consumption of potentially fortifiable foods

Our analysis focuses on five fortifiable foods: wheat flour, rice, salt, oil, and sugar. Wheat flour includes white and whole wheat flour; oil includes soybean, mustard, vegetable, and sesame oils; and rice includes all rice types except rice flour, puffed rice, and beaten rice. Rice is commonly grown by rural households in Bangladesh, but fortification of home-produced rice in local mills is not planned in the near future. However, in other populations less reliant on their own production, a staple food might be more consistently purchased (and therefore fortifiable).

We focus on estimates for adult men and women. This is because several analyses have already shown that HCES estimates do not work well for children, probably because of missing data on breastfeeding (e.g. Coates et al. 2017). Additionally, current evidence suggests that gender inequities in undernutrition are more pronounced among adults and therefore gender bias in estimation methods is more concerning among adults (Basu, 1993; Akerele, 2011; Tesfay and Abidoye, 2019; Thurstans et al., 2020).

Using different methods and data sources, we computed five possible estimates of food consumption, all measured in g/cap/d, as described in Table 1. In brief, we calculate intakes of each food from:

1. '24HR': 24-hour recall data. We consider 24HR as our reference because it has individual-level portion size data and more detailed methods to quantify recipes and portion sizes, and because we are investigating how to improve HCES estimates in the absence of 24HR data. However, this does not imply that 24HR estimates are error-free – they still carry risk of recall bias, mismeasurement of food quantities, and wide variance due to the within-person daily variation in dietary intakes.
2. HCES-AME: HCES data, using the traditional AMEs as the allocation rule (AMEs given in Appendix A). This is the most commonly calculated HCES dietary estimate (Tang et al., 2022), which we are aiming to find ways to improve.
3. HCES-local: HCES data, using locally derived quantity corrections and allocation rules for each food, described in more detail in Section 5. The allocation rule is the median food intake ratio relative to adult men from a subsample of 140 households, also given in Appendix A.
4. 'Allocation corrected': Estimate from HCES data, but using each household's own allocation ratio as observed in the full sample of 24-hour recall data to eliminate error from AMEs.
5. 'Quantity corrected': Estimate from 24HR data, summed to give a total g/d for the household to eliminate error from measurement of household-level quantities, but allocated using traditional AMEs.

For the five different estimates of all five foods, we describe gender-disaggregated coverage and mean intakes derived from 24HR and HCES data sources.

We then model the potential contribution to nutrient adequacy from fortifying each of these foods. To do this, we assume universal fortification of each food and follow current fortification standards for Bangladesh according to the Global Fortification Data Exchange (2021). This was calculated as daily grams of consumption (from 24HR and HCES data), multiplied by fortificant per gram. Then, for each food, measurement method and gender, we describe the proportion of the population having adequate intakes (above Average Requirements) and excess intakes (exceeding Upper Limit cutoffs), using harmonized estimates from Allen et al. (2020). We assume 15% bioavailability of iron due to the high levels of iron in groundwater in many parts of the

Table 1
Estimates of food consumption.

Intake estimate	Data source	Calculation [a]
'24HR': 24-hour dietary recall estimate (reference)	24HR	***individual g/d*** Intakes of the food from all dishes and meals were summed for each person. Intakes of foods included in mixed dishes assumed the individual's proportion of the total cooked dish is proportional to the raw ingredient intake. When missing recipe information on purchased foods, grams of each food contained in the item were imputed from the median recipe proportions given by households in the surrounding administrative district.
'HCES': Estimated intake using household-level data and AMEs (standard method)	HCES, with allocation rules based on AMEs, estimates	***HCES household g/d ÷ household AME × individual AME*** Where 'individual AMEs' correspond to estimates of energy requirements (as per FAO/WHO/UNU (1985)) based on age and gender given in roster data, and are scaled to the reference adult male (AMEs given in **Appendix A).** 'Household AME' is the AME summed for each household member, and is analogous to household size.
'HCES-local': Estimate using HCES data, allocating to individuals using the median allocation ratio from a sub-sample of 140 HHs	HCES, with allocation rule based on a sub-sample of dietary intake surveys from 140 households	***HCES household g/d ÷ household total median ratio × individual median ratio*** Where 'individual median ratios' are the proportion of each food allocated to women relative to men, based on a randomly selected sub-sample of 140 households. These local allocation ratios for each age-sex group are given alongside the AMEs in **Appendix A.** Note: Although our analyses do not focus on children, we still needed to define allocation ratios for all ages so we could calculate a household total. Because there were only a few children of each age in the sub-sample, allocation ratios for children were calculated as the predicted value for each age and gender from an OLS regression.
'Allocation corrected' Allocates HCES consumption using each household's allocation rule	HCES with allocation rule as observed from the full 24HR dataset	***HCES household g/d ÷ household total ratio × individual's own ratio*** Where each household has their own allocation rule,

(continued on next page)

Table 1 (*continued*)

Intake estimate	Data source	Calculation [a]
		based on the 24-hour data for that household.
'Quantity corrected' Allocates 24HR consumption using AMEs	24HR with AMEs	***24HR household g/d* ÷ *household total AME* × *individual AME.*** Where 24-hour dietary recall estimates of food consumption are summed across all household members, to give a total for the household based on 24-hour recall data.

[a] We flagged extreme outliers as individuals with an intake exceeding the 75th percentile by three times the interquartile range (Dary and Imhoff-Kunsch, 2010), and examined and excluded implausible values.

country (Merrill et al., 2011), low bioavailability for zinc (25% for women, 18% for men according to IZiNCG guidelines (Brown et al., 2004)), and convert folic acid to folate using a conversion factor of 1.7. These estimates therefore illustrate how different methods would differentially estimate the potential nutrient contributions of food fortification, and do not incorporate intakes from unfortified diets or other sources such as supplements.

2.4. Measuring bias and agreement

We calculated bias in two ways: Percentage error, calculated as: [estimate – ref] / ref * 100, where the estimate is an HCES measure and the reference is 24HR, and mean difference between estimates, with a test for whether this is larger than zero. These analyses account for the stratified cluster sampling and weighted survey design.

We show agreement in two ways: Bland-Altman (BA) plots, and Cohen's Kappa. BA plots display the difference between HCES and 24HR estimates on the y-axis, plotted against the mean intakes for the two methods on the x-axis. The mean difference between estimates (not adjusted for survey design) is plotted, along with limits of agreement at 5% significance level (mean difference ± 1.96 SD) to depict the variance in the differences between measures. Bland-Altman plots are recommended for assessing agreement between two continuous measures, and are preferred over measures of correlation (or concordance correlations) because they allow visual inspection of the extent to which measures agree over the whole distribution, with less sensitivity to sample heterogeneity (Atkinson and Nevill, 1997). However, they require user-informed judgment to define 'acceptable' limits of agreement, depending on the intended use of the data. Additionally, although the assumption of independence of scores may not hold due to clustering within Primary Sampling Units, we find very similar limits to those calculated from the mean differences that do account for survey design.

We use Cohen's Kappa to examine whether there are differences in classification of households as consumers or non-consumers of each food. To do this, we calculate the probability of observed agreement (P_o), the probability of expected agreement (P_e) that would occur by chance. Cohen's Kappa, κ, combines these two probabilities as: $\kappa = [P_o - P_e]/[1 - P_e]$. Cohen's Kappa is recommended for binary (non-ordinal) variables and allows us to discount agreement that would occur by chance (Ragnanathan, Pramesh, and Aggarwal, 2017). Since the κ statistic on its own may be less easily interpretable, we also report P_o and P_e.

3. Food item coverage, intake, and the potential of micronutrient fortification

In this section, we compare HCES and 24HR estimates of coverage and intake, and the potential contributions of fortifying rice, wheat flour, oil, salt, and sugar. We show that agreement between HCES and 24HR estimates of coverage varies by food type, with stronger agreement for ubiquitously consumed foods (rice, oil, and salt), and more discrepancy for episodically consumed foods (wheat flour and sugar). For intakes, we show that HCES *overestimates* consumption quantities of all foods studied aside from wheat flour (but to varying degrees), but *underestimates* women's share of these foods. HCES and 24HR provide similar overarching conclusions of the potential impacts of food fortification, although HCES estimates would overestimate potential impact of oil fortification, fail to detect gender inequalities in sugar fortification, and overestimate men's risks of exceeding upper levels of iodine from salt fortification.

3.1. Coverage estimates of fortifiable foods

The percentages of men and women consuming any fortifiable foods are given in Fig. 1**.**

Rice, oil, and salt are almost ubiquitously consumed by men and women, irrespective of measurement method. However, only around 1 in 2 adults consume any purchased (and therefore fortifiable) rice – information only available with the HCES data and not routinely collected in 24HR data. Although measurement methods do not necessarily agree on the 1 or 2% who do not consume these foods (notably oil), coverage is so high that this is not likely to be of practical concern.

In contrast, wheat flour and sugar are episodically consumed, and differences in coverage estimates emerge depending on the data source. Overall, the HCES data give higher coverage estimates for these foods than 24HR data, likely because a week's supply is not used every day. However, the 24HR data capture instances of food consumption outside of the home that HCES data do not (17% households for wheat flour; 45% for sugar), and gender differences in coverage estimates (particularly for sugar, driven by men commonly consuming sugary *chai* outside of the home). These discrepancies lead to only modest agreement between HCES and 24HR in their identification of wheat flour and sugar consuming households. For wheat flour, the probability of households being identically classified as a consumer or non-consumer by both methods was 72%, which is significantly ($p < 0.001$) higher than what would occur by chance (54%; Cohen's κ (SE) 0.38 (0.01)). For sugar, the probability of households being identically classified by both methods was 67%, which is slightly but significantly ($p < 0.001$) higher than agreement expected by chance (56%; Cohen's κ (SE) 0.24 (0.01)).

3.2. Intake estimates of fortifiable foods

Fig. 1 also shows mean food intakes for consumers, by gender and measurement method. As expected for the main staple food of Bangladesh, consumption of rice is high (mean 24HR: men 460 g/d; women 407 g/d), whereas consumption of wheat flour is much lower (mean 24HR: men 144 g/d; women 120 g/d), and mean consumption of oil, sugar, and salt is <30 g/d for each.

Table 2 reports intra-household allocation and quantities of food consumption – the two main sources of bias in intake estimates.

Median household allocation ratios fall between 0.96 and 1.00 for all foods, so women receive significantly higher shares than AMEs would predict (AMEs specify an allocation ratio of 0.79 for women:men aged 18–29 years). Allocation ratios also vary widely between households – most strikingly for sugar. Since households allocate larger shares of these foods to women than specified by AMEs, the application of AMEs to HCES data generates underestimates of women's intakes. However, the gender differences in intakes do not vary much between methods in absolute terms because consumption levels are (reassuringly) below 30 g/d (Fig. 1**)**. The implications of these biases for using HCES to estimate risk of populations meeting and/or exceeding nutritional needs are discussed in Section 3.3.

In addition to erroneous allocation rules, both HCES and 24HR estimates are vulnerable to error in measurement of household-level

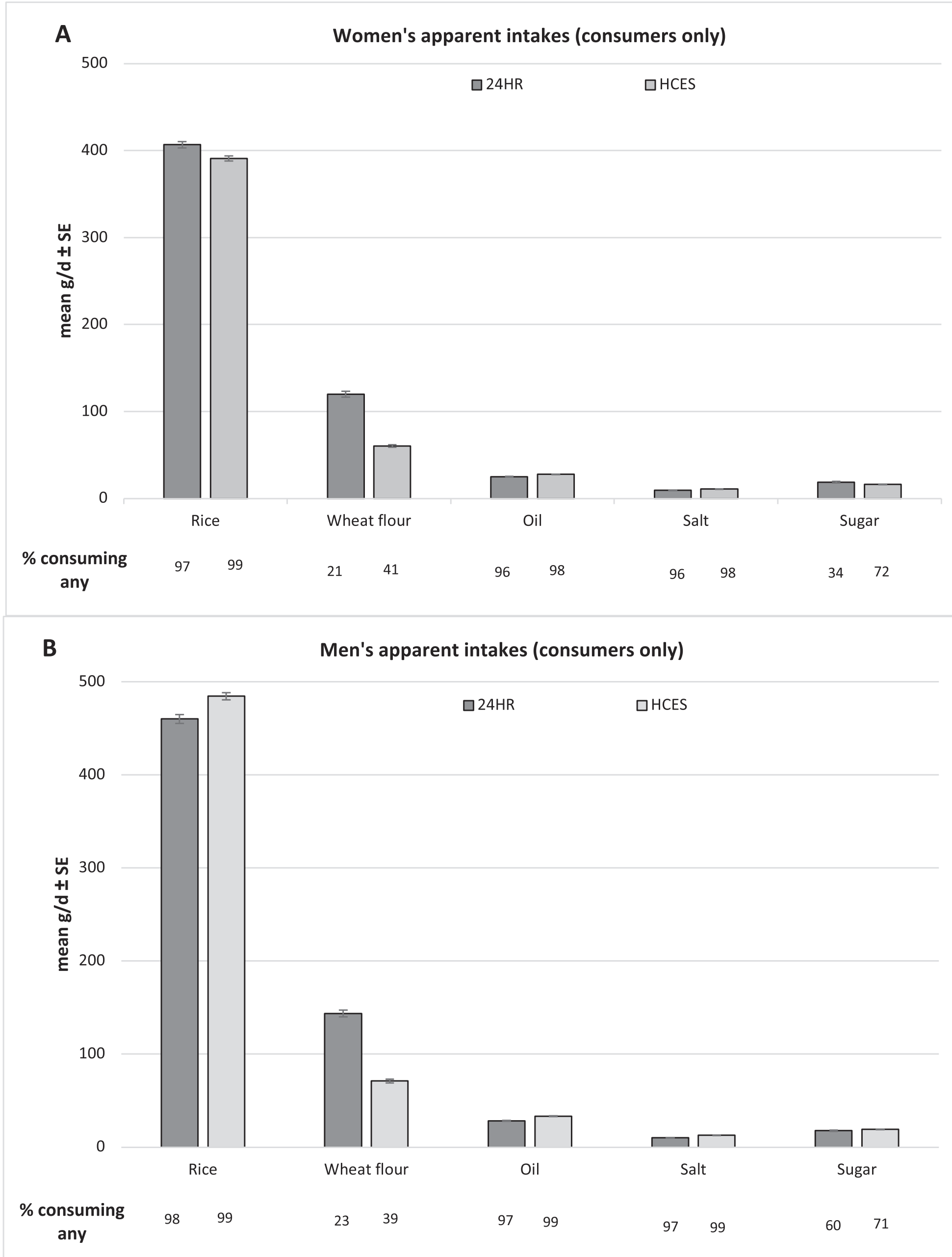

Fig. 1. Apparent intakes and coverage of five fortifiable foods, for women (panel A) and men (panel B). Note: Error bars indicate standard errors. Rice refers to purchased rice only.

quantities. Table 4 compares these estimates. Consistent with other analyses of BIHS data, the mean percentage error shows that HCES data generally overestimate intakes, with the greatest overestimate in absolute terms being rice (at 164 g/day; 1/3 of an average portion), and the greatest overestimate in relative terms being salt (by 11 g/day; median error of 35%). HCES also over-estimate oil and sugar consumption.

The exception is wheat flour, which deserves more explanation. Mean wheat flour estimates are approximately equal, but median percentage error is −56%. These differences in intake distributions are attributable to the different recall periods and the fact that wheat flour is only episodically consumed. This episodic consumption results in 24HR estimates detecting fewer consumers and higher intake estimates on consumption days. HCES estimates spread consumption over the 7-day period, giving an approximation of 'usual' intakes that result in lower consumption in a larger sub-population of consumers. On average, these differences approximately even out, giving very similar mean intakes in 24HR estimates but a large median percentage error.[2] Further recipe analyses show that wheat flour is used for different purposes; many households use a little flour to thicken a gravy, whereas others consume flour in larger quantities to make flatbreads like *roti*.

Apart from wheat flour, our observation that HCES generally overestimates consumption is consistent with other analyses of BIHS data (Karageorgou et al., 2018; Coates et al., 2017). However, the level of

[2] If we were to compare mean intakes of the two different subpopulations of consumers (i.e. 24HR mean if 24HR > 0 and HCES mean if HCES > 0) we would find large differences in mean intakes between methods. For 24HR, we have 1754 consumers, and mean (SD) wheat flour intake of 321 (282) g/d. For HCES, we have 2152 consumers, and mean (SD) wheat flour intake of 263 (194) g/d.

Table 2
Summary of sources of bias when comparing HCES and 24HR methods.

Description of bias	Rice (all)	Rice (purchased)	Wheat flour	Oil	Sugar	Salt
Households consuming any in 24HR or HCES (n)	5604	3227	2742	5604	4726	5598
Intra-household allocation estimation						
HH allocation ratio (women/men) according to 24HR median	0.96	1.00	1.00	0.96	1.00	0.98
[25, 75 centile]	[0.77, 1.02]	[0.94, 1.12]	[1.00, 1.00]	[0.76, 1.00]	[0.00, 1.00]	[0.80, 1.03]
Household allocation ratio – AME Mean difference (SE), *p-value*	0.193 (0.006) $p < 0.001$	0.209 (0.007) $p < 0.001$	0.187 (0.142) $p < 0.001$	0.177 (0.006) $p < 0.001$	0.235 (0.122) $p < 0.001$	0.207 (0.006) $p < 0.001$
Quantity estimation						
Median percentage error in household consumption (HCES − 24HR) ÷ 24HR × 100	11%	10%	−52%	23%	28%	35%
24HR – HCES g/d for household Mean difference (SE), *p-value*	−168 (8) $p < 0.001$	*−79 (6)* $p < 0.001$	1.5 (3) $p = 0.644$	−19 (1) $p < 0.001$	−19 (1) $p < 0.001$	−11 (0) $p < 0.001$

Note: Total households N = 5604. 24HR = 24-hour dietary recall; AME = Adult male equivalent; HCES = Household consumption expenditure survey. Intra-household allocation ratios outliers with values > 3 were excluded from median, 25th percentile, and 75th percentile calculations.

overestimation is variable, and may not necessarily hold for other food items, or indeed the same foods in another context. Discrepancies in HCES and 24HR may also depend on other food-specific factors, such as frequency of purchase, food source (own production), and perishability (Friedman et al., 2017).

3.3. Potential impacts of fortifying rice, wheat flour, oil, salt, and sugar

We now compare the conclusions that we derive from using HCES and 24HR to model the potential impacts of food fortification. Table 3 reports HCES and 24HR estimates of the proportion of men and women who would consume nutrient intakes at or above the average requirements (ARs) and upper tolerable levels (ULs) if 100% of each food was fortified according to current Bangladesh specifications. Despite both data sources having differences sources of error[3], they agree that rice, oil and salt are good candidates for fortification (the latter two already being fortified in Bangladesh), whereas wheat flour and sugar fortification would be less effective.

We first consider rice, which HCES and 24HR both agree is a good candidate for fortification. Since HCES estimates are higher than 24HR estimates, HCES data slightly over-estimate the reduction in micronutrient inadequacies for both men and women. Both data sources identify a high risk of adults exceeding upper limits for folate (and zinc to a lesser extent) through consumption of fortified rice alone, suggesting that fortification standards may need to be adjusted.

For wheat flour, both HCES and 24HR agree with the overall conclusion that wheat flour fortification would not be effective.[4] Even among the small proportion who do consume any, 24HR estimates (which are more optimistic than HCES) show that large proportions would not meet their requirements for vitamin A, folate, iron, and zinc, and there is almost no risk of men or women exceeding upper levels for these nutrients.

For oil, we see differences in the potential contributions of oil fortification depending on estimates used: 24HR estimates show around half of adults consuming oil would meet vitamin A requirements, whereas the HCES estimates show over two-thirds of adults would. However, the overall conclusion is the same: given that oil is already fortified with vitamin A in Bangladesh (61% of oils currently fortified (GAIN, 2016)), further spread of fortified oil in Bangladesh would increase vitamin A adequacy with low risk of exceeding upper limits.

For salt, both methods show that fortification would meet almost all iodine requirements and there may be some risk of exceeding upper limits. Bangladesh has been fortifying salt with iodine since 1989, with an estimated 69% of salt iodized. The HCES intakes over-estimate the potential risk of exceeding upper limits of iodine through salt fortification, especially for men (HCES 18% vs 24HR 8% above UL).[5]

We do not model the potential contributions of fortifying sugar because current fortification standards for Bangladesh have not been defined. However, HCES and 24HR data do not agree on coverage estimates (which range from 34% to 72% depending on gender and measurement method). There are also large age and gender gaps in sugar coverage, so sugar fortification would widen existing gender gaps in micronutrient deficiencies.

3.4. Implications for HCES design and analysis

Taken together, we show that HCES estimates can be sensibly used to model potential population-level impacts of fortifying rice in Bangladesh. This is because it has almost ubiquitous coverage and is consumed in large quantities. A notable strength of the HCES data (that is lacking from the 24HR data) is the information on food source, which allows us to identify the proportion of the population that purchases rice and is therefore industrially fortifiable.

For episodically consumed foods (especially sugar), large gender-biased differentials in estimates emerge, both in terms of potential reductions in nutritional inadequacy and potential risk of exceeding upper tolerable nutrient levels. This is largely because HCES estimates smooth weekly consumption over the 7-day period, so they estimate higher coverage but lower consumption among consumers. HCES estimates could be improved by collecting data on the consumption of foods consumed outside of the home, and perhaps by collecting gender-disaggregated data on foods of particular concern for nutrition programmers (such as fortifiable foods, junk foods, and micronutrient-rich foods).

To set fortification standards for foods consumed in small quantities, such as salt and oil, HCES data should be avoided. HCES are not

[3] As noted earlier, we expect to have inflated variance for both 24HR and HCES estimates due to wide within-person variability in diets and measurement error. With the exception of wheat flour, the intake distribution *widths* for foods studied are very similar between 24HR and HCES (results not shown), and we have shown earlier that HCES distributions have a *right-shift* (Table 2). This means that, compared with the unobserved true usual intake, 24HR will overestimate deficiency and excess from fortification of these foods. On the other hand, compared with the true usual intake, HCES will overestimate excessive intakes (even more than 24HR). Implications of using HCES to estimate deficiency are difficult to discern because they depend on extent of dispersion and bias relative to the true intake.

[4] This finding is consistent with Fiedler et al. (2015) and the fortification opportunity assessment of the Global Fortification Data Exchange (https://fortificationdata.org/country-fortification-dashboard/?alpha3_code=BGD&lang=en).

[5] The high intakes of salt are concerning, with average consumption levels are approximately double the WHO recommendation of max 5 g/d. However, measurement error is likely to be high, since consumption was measured to the nearest gram, and precise estimates require precise measurement.

Table 3
Comparison of predicted prevalence of micronutrient adequacy and excess through consumption of fortified foods, by measurement method and gender.

Nutrient	Gender and estimation method	Wheat flour		Rice		Oil		Salt	
		% Adequate	% Over	% Adequate	% Over	% Adequate	% Over	% Adequate	% Over
Vitamin A	Women 24HR	21.76	0.00	84.13	0.00	52.66	0.00		
	Men 24HR	25.09	0.00	80.77	0.00	49.8	0.00		
	Women HCES	3.64	0.00	86.98	0.00	67.39	0.00		
	Men HCES	3.85	0.00	88.55	0.00	69.04	0.00		
Folate	Women 24HR	75.15	2.53	99.38	59.23				
	Men 24HR	80.36	5.45	99.41	67.24				
	Women HCES	33.6	0.00	99.62	55.88				
	Men HCES	42.47	0.29	99.66	76.83				
Iron	Women 24HR	21.55	0.00	92.02	1.06				
	Men 24HR	50.62	0.00	98.19	3.68				
	Women HCES	3.55	0.00	93.31	0.81				
	Men HCES	13.06	0.00	99.61	3.58				
Zinc	Women 24HR	0.62	0.00	82.26	5.49				
	Men 24HR	0.07	0.00	73.99	11.73				
	Women HCES	0.00	0.00	84.27	3.77				
	Men HCES	0.00	0.00	83.32	12.46				
Iodine	Women 24HR							98.09	6.40
	Men 24HR							98.22	8.83
	Women HCES							99.69	7.55
	Men HCES							99.79	17.64

Note: All intake estimates refer to the population of consumers only. For all nutrients apart from iron, we determine % adequate and % over via the cut-point method, reporting % above the average requirements or upper levels as defined by Allen et al (2020). For iron, we use the USA Institute of Medicine's probability approach, assuming 15% bioavailability of iron.

designed to accurately measure consumption of specific foods in small quantities; repeated 24HR or prospective weighing methods should be used to inform fortificant concentration standards for these foods. If HCES are being collected with such applications in mind, better methods for measuring quantities are needed. This could draw on technologies developed in nutritional science, such as active and passive wearable cameras to estimate quantities, although further work in this area is still needed to ensure their precision (Höchsmann and Martin, 2020).

4. Decomposition of bias and agreement in estimation of intakes

Most studies comparing HCES and 24HR estimates focus on *mean bias;* few focus on levels of *agreement* between methods. Agreement matters because measures like mean bias allow over- and under-estimates to cancel each other out, masking the total error. In this section, we describe and decompose sources of bias and agreement. We show that comparisons of mean bias alone masks poor and heteroskedastic agreement between measures, primarily due to disagreement in quantity estimates rather than intra-household allocation.

Agreement is shown with Bland-Altman plots in Fig. 2. The Bland-Altman plots show differences between estimates plotted against the mean consumption. The central dashed lines show the mean difference between methods, which are relatively small (consistent with what we see in Fig. 1). The dashed lines either side of the mean difference line show the 'limits of agreement', which are set at ±1.96 SD of the mean difference. For all foods, upper and lower limits are very wide – in fact, they have similar magnitude to the mean intake level. This is around double the width of agreement that is found in dietary assessment tools comparing the validity of 24HR methods versus prospective weighing methods (e.g. Turconi et al., 2005). All foods show wide heteroskedasticity in agreement, showing closer agreement at smaller consumption levels, especially for wheat flour and sugar.

So far, we have shown varying levels of mean bias and very wide limits of agreement, and we have described two main reasons for this: errors in measurement of quantities consumed by the household, and errors in the AME allocation rule used to individualize household-level data. This raises questions as to what levels of bias and agreement would occur by chance, and also how far they would improve by correcting the quantities or the allocation rules. To answer this, we create three scenarios:

- 'No agreement', which is the mean bias and agreement between 24HR and HCES that would occur by chance (if there was no connection between each individual's two measures).[6]
- 'Allocation corrected', which is the mean bias and agreement between 24HR and HCES after we correct for inaccurate AME assumptions (by using allocation rules as observed in the 24HR data but keeping the HCES household consumption estimate).
- 'Quantity corrected', which is the mean bias and agreement between measures after correcting for errors in household quantities. This compares 24HR with the estimated intake from summing 24HR across the household and then applying AMEs.

For each scenario, we calculate the agreement as the width of upper and lower limits of agreement (upper 95% CI minus lower 95% CI). We then compare the agreement in each scenario against the agreement observed between the 24HR and the HCES, and report the percentage differences in Fig. 3.

Reassuringly, the limits of agreement are wider in our scenario of what would simply occur by chance, particularly for foods consumed in larger quantities (rice and wheat flour), and to a lesser extent for foods consumed in smaller quantities (oil, sugar, and salt). We also see that correcting measurement error in quantification is more important than correcting the intra-household allocation. Correcting for measurement error in quantification narrows the limits of agreement for women's

[6] To do this, we delink the one of the intake measures from their unique person identifier and randomly re-order it to create a scenario where we would expect zero agreement with the other measure (beyond chance).

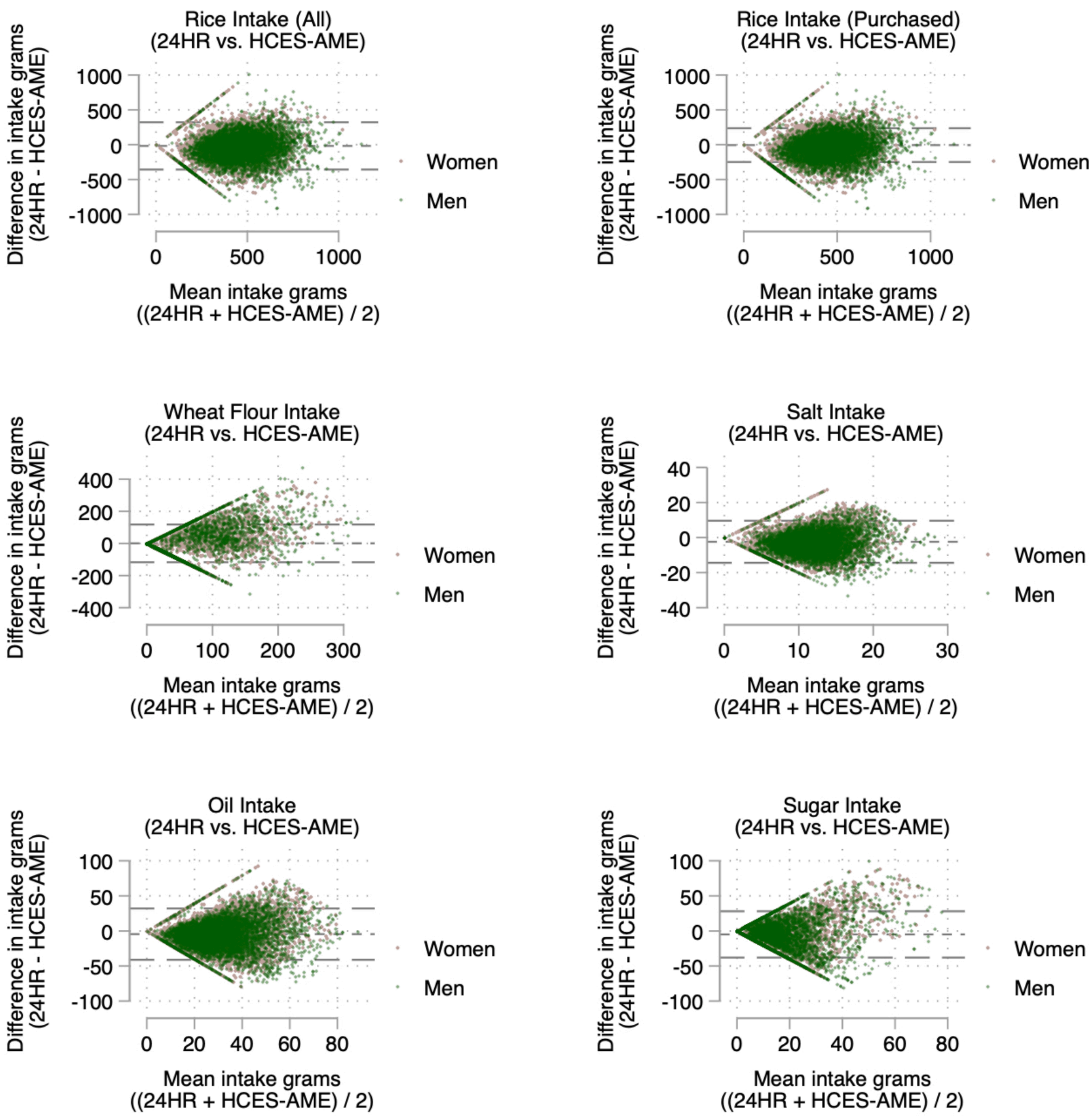

Fig. 2. Bland-Altman plots illustrating levels of agreement between HCES and 24HR.

intake by 37% for rice, 43% for wheat flour, 52% for oil, 55% for sugar, and 54% for salt. Correcting the allocation rules narrows the limits of agreement for women's intake by 13% for rice, 25% for wheat flour, 4% for oil, 15% for sugar, and 1% for salt. Similar trends are observed for men.

This indicates that, depending on the research question, a combination of methods may be needed to improve both quantity estimates and allocation rules. It is possible that agreement in quantity estimates would be higher if we were comparing HCES against repeated 24HR estimates, although the width of the intake distributions for all ubiquitously consumed foods are very similar with HCES and 24HR data.

5. An alternative approach to using HCES data

So far, our analyses have given Bangladesh-specific descriptions of different sources of bias, with conclusions about the validity of using HCES data that are not easily extrapolated to other contexts or other foods not studied in this paper. As we have described in our introduction, there is high heterogeneity between contexts in both intra-household allocative norms and bias in the quantification of household consumption. This indicates a need for locally specific information to correct these two major forms of bias.

Since it is rare for countries to undertake such extensive assessments of intra-household food allocation as we have with BIHS, we propose a simple method of using dietary data from a small sample of households to improve HCES estimates. This could use data that may already exist in some settings or could feasibly be collected. In our case, to illustrate the proof of concept, we draw a random sample of 140 households from the 24HR in BIHS.

Our method is described in Fig. 4. In brief, we select intra-household food allocation data from a random sample of 140 households from the BIHS dataset and, for each food studied, calculate difference in mean household consumption between HCES and 24HR subsample, and median intra-household allocation ratios in the 24HR subsample. These are then applied as corrections to the HCES data. We report the impact on mean bias estimates of applying these quantity corrections and replacing AMEs with locally derived allocation rules.

This number of 140 households (20 per administrative division) was chosen pragmatically, because 24-hour dietary intake surveys of 100–200 households are often feasible (e.g. studies reviewed in Torheim

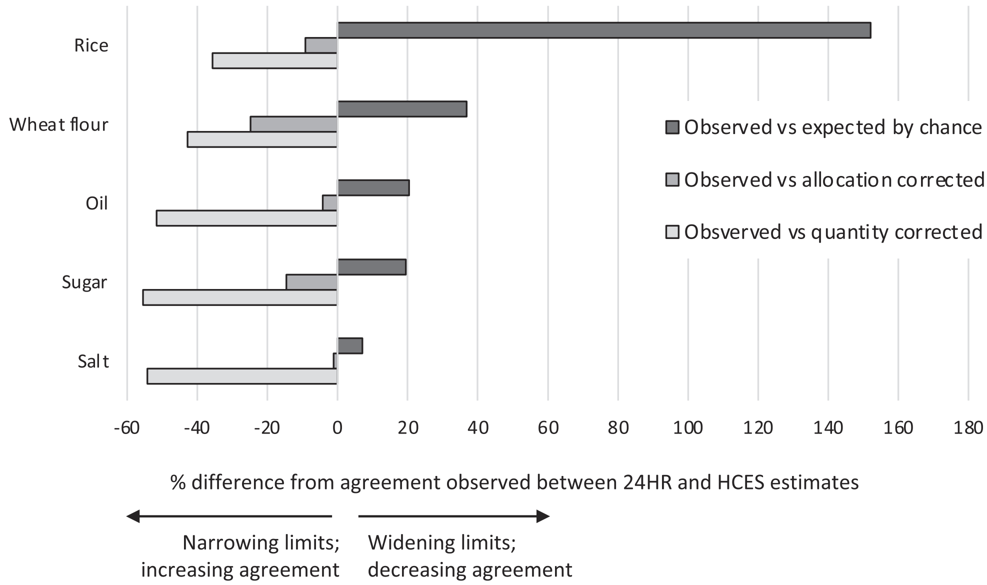

Fig. 3. Percentage difference in agreement by chance, agreement after correcting the allocation, and agreement after correcting household quantities, each relative to agreement observed between HCES and 24HR for women.

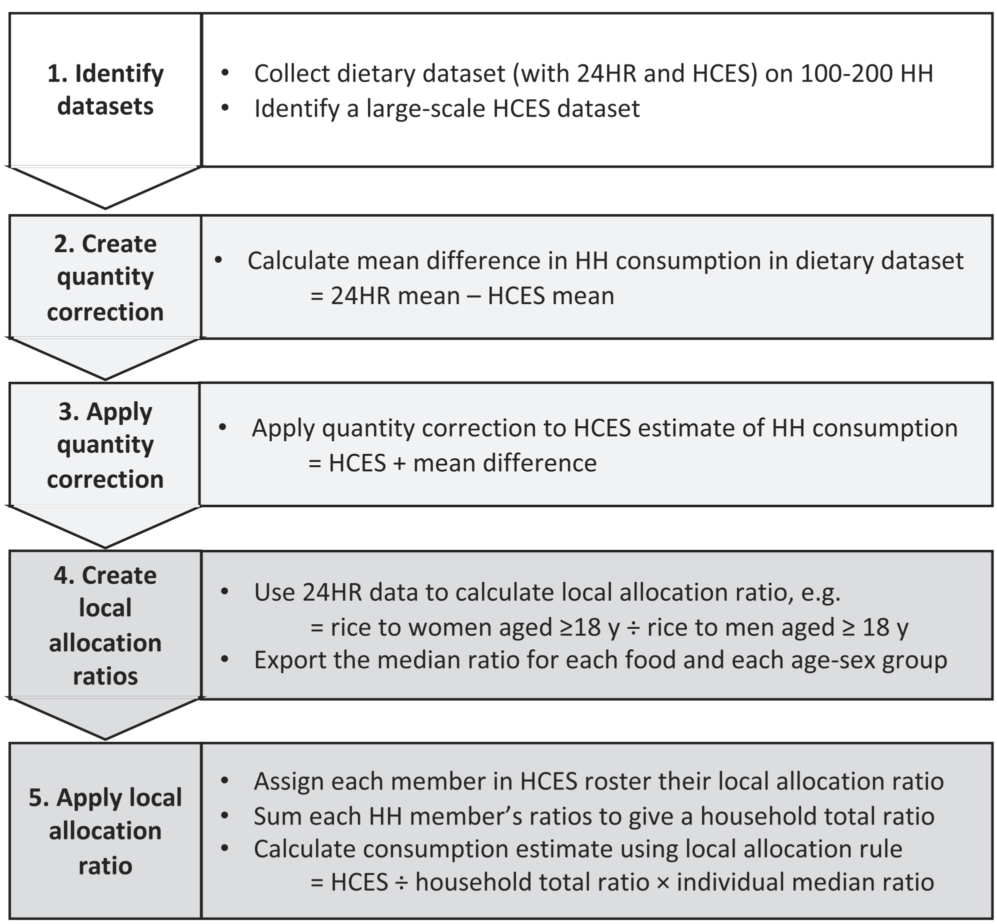

Fig. 4. Method of correcting bias in HCES consumption estimates.

et al. (2010)). This means that this approach of using food-specific allocation ratios could be realistically adopted in other settings, and could offer an 'in-between' solution that improves estimates from HCES whilst being more feasible and affordable than conducting a nationally representative dietary intake survey. Additionally, existing datasets of around this size in other places might already exist and could be used.

Our results (Table 4) show that this method to generate 'HCES-local' estimates can substantially reduce the percentage error, almost eliminating mean bias of ubiquitously consumed foods (rice, oil, and salt). It is particularly useful for improving HCES estimates of oil and salt, which

Table 4
Comparison of intakes and % error using HCES with AMEs vs HCES using locally derived corrections.

Food	*n* consumers in sub-sample	24HR		HCES-AME			HCES-LOCAL		
		Intake	(SE)	Intake	(SE)	% error from 24HR	Intake	(SE)	% error from 24HR
Nearly ubiquitously consumed foods									
Rice									
Men	186	451	(4.5)	482	(3.7)	7	445	(3.9)	−1
Women	196	390	(3.8)	389	(2.8)	0	394	(3.3)	1
Oil									
Men	182	27	(0.4)	33	(0.4)	21	25	(0.4)	−8
Women	193	24	(0.3)	27	(0.3)	15	23	(0.3)	−2
Salt									
Men	186	10	(0.1)	13	(0.1)	30	10	(0.1)	−3
Women	196	9	(0.1)	11	(0.1)	19	9	(0.1)	1
Episodically consumed foods									
Rice (purchased)									
Men	86	216	(6.8)	231	(7.2)	7	363	(4.1)	68
Women	96	205	(5.7)	199	(5.4)	−3	354	(3.6)	73
Wheat flour									
Men	34	33	(1.9)	27	(1.4)	−16	57	(1.8)	75
Women	36	24	(1.5)	25	(1.2)	2	57	(1.6)	138
Sugar									
Men	104	10	(0.4)	14	(0.3)	31	13	(0.3)	23
Women	63	6	(0.4)	12	(0.3)	101	13	(0.3)	123

Note: $N = 192$ men and 204 women.

have high levels of error (15% to 30%) using the traditional method, and far lower error after applying these locally-derived quantity and allocation corrections (% error: −8% to 1%).

For completeness, we show how the method performs for episodically consumed foods. However, given the lack of repeated 24HR measures, it is likely that HCES give estimates that are closer to 'usual' intakes (spreading weekly consumption over a 7-day period). Additionally, for these foods, the number of consumers in this small sample of households will be much lower, meaning that corrections may be less reliable. For this reason, corrections to HCES using 24HR estimates are not useful for episodically consumed foods – at least in our case where we only have a single dietary recall per person to draw from.

5.1. Caveats to the application of HCES-local estimates

We note five caveats to this method. The first obvious concern with using this approach is that we have drawn a small sub-sample that is not designed to be nationally representative. To examine this, we descriptively compare respondent characteristics in the 140 households against the full sample. The mean socioeconomic and demographic factors in our subsample were very similar to the full sample **(Appendix B)**. We also illustrate the extent to which our conclusions could vary, by drawing 100 random samples and plotting mean and variance in intakes for women in each draw **(Appendix C).** We show generally consistent estimates, suggesting that this method could be reliably used to inform and refine HCES estimates. Relatedly, it is possible that 24HR data used to generate allocation rules from other sources or settings would not be as dispersed across the country as our random sample was. Existing 24HR datasets have usually been collected in smaller geographical regions, sometimes because they are particularly poor or gender-unequal. In our case, we find no clear differences by geographic division, suggesting that spatial heterogeneity in allocation rules is not a concern in this context – likely because of very high heterogeneity within divisions. In other cases, the 24HR may be less representative of the country. However, we suggest that these allocation rules are at least an improvement to arbitrarily defined AME allocation rules, and could be used in conjunction with AME to test the robustness of conclusions using AMEs. Replication in other settings is needed.

Second, as mentioned, this method is appropriate for correcting estimates of ubiquitously consumed foods. In a small sample of 140 households, and a smaller sub-sample of consumers, we obtain very small sample sizes to generate intra-household allocation rules. This is particularly relevant in our case because we only have a single day of dietary recall per respondent in the BIHS, so we are unable to predict usual intakes using standard methods that are possible with repeated recalls. In future work, researchers could test this approach on episodically consumed foods using data with replicates of 24-hour dietary recalls. We examined whether doubling this random sample to 240 households could improve the estimates (particularly for episodically consumed foods where mean bias remains high). However, increasing this sample did little to improve the estimates.

Third, if we apply locally derived median allocation rules to HCES data without also correcting for the mean bias in household consumption, we generate estimates for women that have larger mean bias than using the traditional AME approach. This is because HCES *overestimate* consumption quantities but AMEs *underestimate* women's share of these foods. Therefore, only correcting one form of bias worsens the estimates for women, and both corrections are needed.

Fourth, these corrections are identically applied to all individuals in the sample. So, this method can only meaningfully reduce the mean bias and will not improve agreement between estimates. We explored whether estimates could be further improved by making more specific local allocation rules, as this would improve agreement as well as mean bias. However, additional analyses showed that simple factors such as geographic division, religion, literacy, wealth, household size, and gender of the main decision-maker in the household, did not explain much of the variation in these allocation rules. We therefore did not create further divisions of the small sample to create more specific allocation rules. Better understanding of the sources of heterogeneity in intra-household food allocation and improvement in quantification methods are needed, ideally in combination with this method, to correct the mean bias. Further work could also explore the implications of this method for other age groups.

Finally, we note that a simpler approach is to just describe allocation and consumption in this sub-sample, rather than apply corrections to the HCES data. However, since we have shown that HCES estimates do somewhat agree with 24HR estimates on identification of consumers and quantity estimation (far more than would occur by chance), and there are some advantages of the HCES data (namely the large sample size, 7-day recall period, and data on food source to identify rice purchasers), we think that this combined approach offers a realistic 'in-between' solution that draws on the strengths of both data sources.

6. Discussion

Our study has illustrated the public health and gender equity implications of using HCES data to estimate men's and women's food intakes in rural Bangladesh and proposed a method to improve HCES estimates that can be applied to any context.

6.1. Implications for policy and research in Bangladesh

In terms of public health implications, we show that HCES and 24HR data agree on many of the major conclusions about the potential benefits and risks of food fortification in rural Bangladesh. That is, rice, oil and salt make good candidate foods for fortification, whereas wheat flour and sugar fortification would be less effective. Fortifying rice, oil, and salt according to current recommendations would resolve dietary inadequacies of multiple micronutrients (including vitamin A, folate, iron, zinc, and iodine) for most of the men and women who consume any of these foods. Further scale up of current oil and salt fortification efforts is recommended. Rice fortification presents a promising intervention to reduce dietary inadequacy in a gender equitable way, ideally in conjunction with other interventions to improve availability, quality and affordability of diverse diets. However, folate and zinc fortification levels may need to be reduced, and fortification with iron may be unsafe due to high groundwater contamination and risk to children with infection (Prentice, Verhoef & Cerami, 2013; Sazawal et al., 2006; Soofi et al., 2013). Additionally, coherence among actors within the nutrition sector is needed, particularly as micronutrient supply is being modified in different ways – for example through fortification of several foods, biofortification, micronutrient supplements, and dietary interventions.

In terms of gender equity implications, we see that Bangladeshi women are allocated much larger shares of the foods studied here than we would predict using AMEs. This mirrors the lower prevalence of underweight and higher prevalence of overweight in women than men reported in the latest DHS report (NIPORT and ICF, 2020). The pro-female bias in the allocation of these energy-dense foods differs from previous analyses of BIHS data showing more pro-male bias in the allocation of other, protein-rich foods, perhaps because these protein-rich foods are less widely consumed and represent 'special', culturally higher status foods like meat, fish, and dairy (Coates et al., 2017). Therefore, although fortification presents one approach to improving nutrition in Bangladesh, social interventions that change gender norms around intra-household food allocation and social mobility are also needed to increase women's intakes of micronutrient-rich foods, reduce over-consumption of energy-dense foods, and increase freedom and opportunities to exercise in a safe environment (Morrison et al., 2019).

Despite the higher-than-expected allocation of these foods towards adult women, we find that the biggest source of error from using HCES data lies in mismeasurement of quantities consumed by the household, rather than the AME allocation rule. In fact, for women, the errors in quantity measurement and allocation assumptions cancel each other out slightly, since HCES tend to overestimate household consumption and AMEs underestimate women's shares. This relatively low mean bias in estimates masks wide and heteroskedastic agreement between HCES and 24HR coverage and intakes estimates. Particularly concerning limitations of HCES are that they do not detect large gender differences in coverage estimates for sugar, and they are not designed to measure individual foods consumed in small quantities (such as oil and salt). In fact, for these foods, HCES and 24HR estimates only agree with each other slightly more than would occur by chance.

This means that, in our study context, HCES data can be reasonably used to generate population-level consumption estimates of commonly consumed foods that are eaten in large quantities. However, they will miss gender inequities in coverage and consumption, and they should not be used for studies requiring higher degrees of validity and precision, such as studies of diet-disease relationships or for setting fortification standards of foods consumed in small quantities.

6.2. Implications for the use of HCES beyond Bangladesh

All of these descriptions of measurement error are specific to rural Bangladesh, meaning that they have important policy implications in this context but have limited external validity. However, three major conclusions could apply to HCES in any setting. First, given that HCES are not usually designed to (primarily) measure food consumption of individual foods in small quantities, it is reasonable to conclude that investment in methods to improve precision of quantity measurements could vastly improve the value of HCES data to inform dietary analyses in any setting. Ideally this would involve nutritionists in survey design, and use methods developed in nutritional science, such as photographic atlases, food models, participant-led photography, or passive wearable cameras (Amoutzopoulos et al., 2020). Nevertheless, we recommend that fortificant standard setting for foods consumed in small quantities should be based on higher-quality data, such as repeated 24HR or prospective weighing over multiple days. Second, the recommendation that HCES should collect data on foods consumed outside of the home can apply universally, as it would improve HCES estimates of consumption in any setting. Third, the recommendation for 24HR methods to collect data on food sources (to identify what proportion of consumption is industrially fortifiable) is also applicable to any context.

However, our conclusion that mean bias in HCES intakes is relatively small, and (relatedly) that measurement error is a bigger problem than the AME allocation assumption, may not hold in other settings or for the study of different foods. As we have described earlier, allocation norms vary widely between food types (Ahmed et al., 2007; Harris-Fry et al., 2017), and between settings (Berti, 2012), as does mismeasurement of food quantities (Coates et al. 2017; Dary and Jariseta, 2012; Engle-Stone and Brown, 2015). Therefore, we cannot confidently conclude that HCES data give unbiased measures of food quantities consumed in large quantities in any other setting than Bangladesh, and it is inadvisable to use a blanket rule (AMEs, or our Bangladeshi allocation rules) to all HCES data around the world.

We demonstrate a simple solution to this, by showing how we almost eliminate mean bias in HCES estimates by applying locally generated corrections to HCES data from a small sample of intra-household food allocation data. We adjust the mean bias in HCES quantities and apply locally- and food-specific intra-household allocation rules, thereby allowing both sources of bias (quantity estimation and allocation assumption) to be simultaneously corrected for. In doing so, we make no assumptions about the relative importance of one source of error over another, and avoid the pitfall of making estimates worse by only correcting for one type of error. This method allows analysts to make use of the strengths of both data types. We conclude that this method presents a sensible 'in-between' solution for researchers who do not have access to large-scale dietary datasets on intra-household food allocation and is especially beneficial for reducing bias in studies of foods consumed regularly but in small quantities.

Further work is needed to test this approach in other age groups, contexts, and ideally with dietary datasets that contain repeated 24HR measures, to test its appropriateness for episodically consumed foods.

Replication studies are particularly important because the HCES and 24HR data in the BIHS may agree more than in other settings, since they were collected by the same organization at the same time of year. Our conclusions also highlight the need to better explain the very wide variance in household allocation norms in this study setting, both for understanding the implications on the validity of using HCES data but also because intra-household equity is an important outcome in its own right.

Given the current and rapid expansion of food fortification programs worldwide, this is a crucial time to ensure the methods applied to HCES data are appropriate. We hope our proposed method will be used to ensure that HCES estimates account for locally-specific measurement error and gender norms, and that food fortification and other nutrition interventions based on these data will be safer and more gender-sensitive.

CRediT authorship contribution statement

Helen Harris-Fry: Conceptualization, Methodology, Formal analysis, Writing – original draft, Supervision. **Lauren Lamson:** Data curation, Formal analysis, Visualization, Writing – review & editing. **Katelyn Roett:** Data curation, Formal analysis, Writing – review & editing. **Elizabeth Katz:** Conceptualization, Funding acquisition, Writing – original draft, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Adult Male Equivalents and local allocation rules

Age	Sex	AME	Rice (purchased)	Rice (all)	Flour	Oil	Sugar	Salt
0	Male	0.22	0.64	0.21	0.79	0.27	0.39	0.31
0	Female	0.22	0.57	0.13	0.73	0.22	0.40	0.28
1	Male	0.31	0.66	0.26	0.80	0.31	0.40	0.35
1	Female	0.28	0.59	0.18	0.74	0.26	0.41	0.31
2	Male	0.37	0.68	0.30	0.81	0.35	0.42	0.38
2	Female	0.34	0.61	0.22	0.75	0.30	0.43	0.35
3	Male	0.41	0.70	0.34	0.82	0.39	0.43	0.42
3	Female	0.38	0.63	0.26	0.76	0.34	0.44	0.39
4	Male	0.44	0.72	0.39	0.83	0.44	0.44	0.46
4	Female	0.41	0.65	0.31	0.77	0.38	0.45	0.43
5	Male	0.48	0.74	0.43	0.84	0.48	0.45	0.50
5	Female	0.43	0.67	0.35	0.78	0.43	0.46	0.46
6	Male	0.52	0.76	0.48	0.85	0.52	0.47	0.53
6	Female	0.47	0.69	0.40	0.79	0.47	0.48	0.50
7	Male	0.56	0.78	0.52	0.86	0.56	0.48	0.57
7	Female	0.51	0.71	0.44	0.80	0.51	0.49	0.54
8	Male	0.60	0.80	0.57	0.87	0.60	0.49	0.61
8	Female	0.56	0.73	0.49	0.81	0.55	0.50	0.58
9	Male	0.65	0.82	0.61	0.88	0.64	0.50	0.65
9	Female	0.61	0.75	0.53	0.82	0.59	0.51	0.62
10	Male	0.70	0.84	0.66	0.89	0.69	0.52	0.69
10	Female	0.66	0.77	0.58	0.84	0.63	0.53	0.65
11	Male	0.77	0.86	0.70	0.90	0.73	0.53	0.72
11	Female	0.70	0.79	0.62	0.85	0.68	0.54	0.69
12	Male	0.84	0.88	0.75	0.91	0.77	0.54	0.76
12	Female	0.75	0.81	0.67	0.86	0.72	0.55	0.73
13	Male	0.91	0.90	0.79	0.92	0.81	0.55	0.80
13	Female	0.78	0.83	0.71	0.87	0.76	0.56	0.77
14	Male	0.98	0.92	0.84	0.93	0.85	0.56	0.84
14	Female	0.80	0.85	0.76	0.88	0.80	0.58	0.80
15	Male	1.04	0.94	0.88	0.94	0.89	0.58	0.87
15	Female	0.82	0.87	0.80	0.89	0.84	0.59	0.84
16	Male	1.09	0.96	0.92	0.96	0.94	0.59	0.91
16	Female	0.82	0.89	0.84	0.90	0.88	0.60	0.88
17	Male	1.11	0.98	0.97	0.97	0.98	0.60	0.95
17	Female	0.82	0.91	0.89	0.91	0.93	0.61	0.92
18+	Male	1.00	1.00	1.00	1.00	1.00	1.00	1.00
18+	Female	0.79	1.00	0.90	1.00	0.92	1.00	0.94

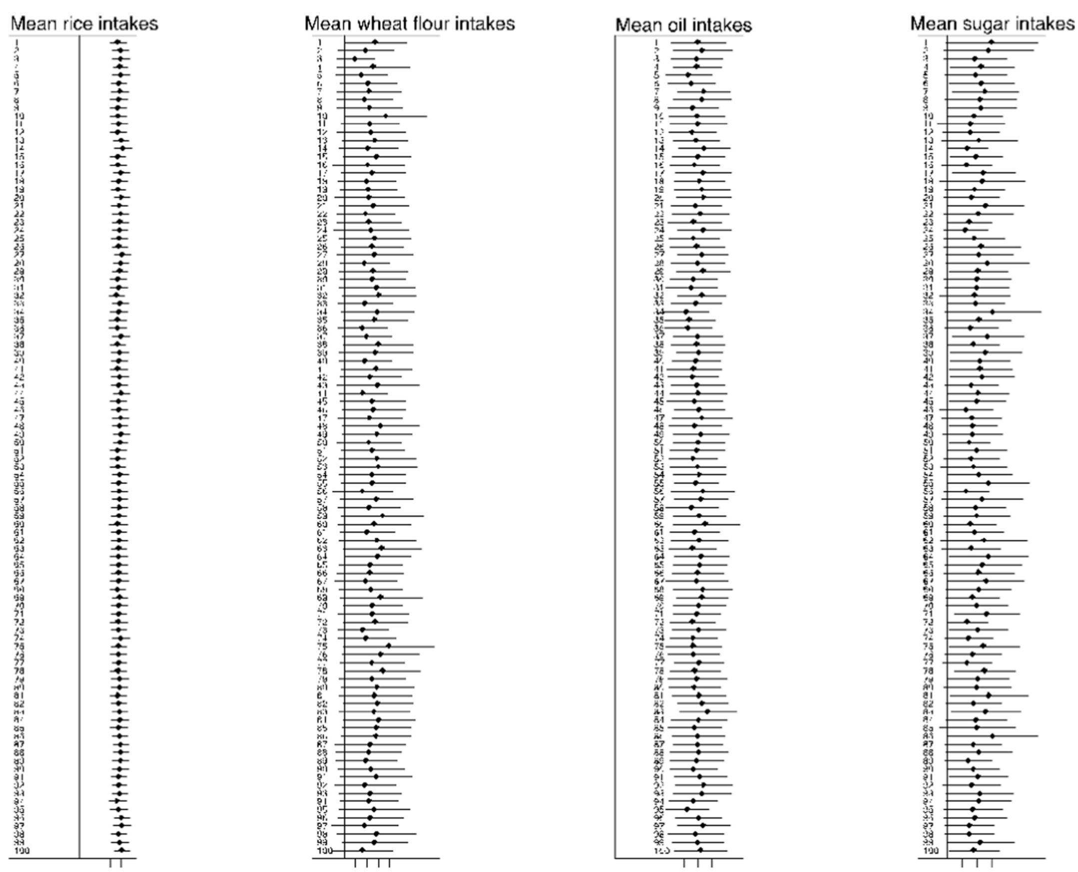
Note: HCES-AMEs for ages 0–18 constructed using predicted values from a linear regression.

Appendix B. Respondent characteristics

	Statistic	Full sample (5604 HHs; 14,097 adults)		Sub-sample (140 HHs; 396 adults)	
		Mean or %	SD	Mean or %	SD
Household Characteristics					
Gender (% women)	Percentage	56%		52%	
Monthly per capita expenses (BDT)	Mean	4348	2242	4358	1928
Number of household members	Mean	5	2	5	2
Main decision-maker in household (% women)	Percentage	20%		4%	
Descriptive variables - Women					
Age (y)	Mean	40	16	44	16
Age at first marriage (y)	Mean	17	3	20	5
Education (y)	Mean	4	4	4	4
Literate	Percentage	59%		59%	
Descriptive variables - Men					
Age (y)	Mean	46	15	48	15
Age at first marriage (y)	Mean	24	4	24	4
Education (y)	Mean	4	4	4	4
Literate	Percentage	61%		59%	
Wealth (by household)					
1st quintile (poorest)	Percentage	14%		7%	
2nd quintile	Percentage	19%		21%	
3rd quintile	Percentage	17%		15%	
4th quintile	Percentage	24%		34%	
5th quintile (least poor)	Percentage	26%		23%	
Religion (by household)					
Hindu	Percentage	10%		12%	
Muslim	Percentage	89%		87%	

Note: Wealth calculated as the first principal component of a principal components analysis of 76 assets.

Appendix C. Women's mean intakes from 100 repeated draws of 140 households



Note: Diamonds indicate means and bars either side indicate standard deviations.

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