Epidemiology of Dietary and Micronutrient Deficiencies in Mongolia

Epidemiology of Dietary and Micronutrient Deficiencies in Mongolia

Sabri Bromage

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Dissertation Advisor: Dr. Wafaie W. Fawzi Sabri Bromage

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Abstract

Background: Extreme characteristics of the Mongolian food supply and diet are associated with severe nutritional risks. Understanding these risks is relevant to the study of global chronic disease, but this understanding is hampered by a lack of research, interventions, and data collection platforms in Mongolia. This dissertation aims to address these deficits by (1) characterizing the distribution and determinants of a particularly severe biochemical micronutrient deficiency in Mongolia, (2) characterizing the distribution of multiple intake deficiencies in Mongolia and designing a specific intervention to address them, and (3) evaluating methods for estimating diet from household food consumption data in Mongolia.

Methods: Summer and winter vitamin D status, and food and nutrient intake were assessed in 320 healthy urban and rural adults across Mongolia. Severity of vitamin D deficiency and its independent predictors were analyzed using multiple regression analyses. Food and micronutrient intake data were used to project the effectiveness of mandatory multiple micronutrient food fortification under different scenarios using the Intake Modeling, Assessment, and Planning Program. Four methods of estimating diet from household food consumption data were applied to two nationally-representative household surveys, and validated against a 24-hour recall nested within one of the two surveys.

Results: Summer and winter serum 25-hydroxyvitamin D concentrations were below 20 ng/mL in 42.4% and 99.6% of the study population, respectively, with independent associations observed between status and season, age, sex, region, urban/rural locality, and sun exposure. Micronutrient intake deficiencies were widespread, particularly of thiamin, folate, and vitamins A, D, and E. Fortification of wheat flour, milk, and edible oil would be effective in addressing these intake deficiencies, is also recommended for iron and riboflavin, and may be unnecessary for zinc, niacin, and vitamin B12.

Comparison of household disaggregation methods revealed each to have particular strengths, weaknesses, and applications.

Co*nclusion*: Micronutrient deficiencies and dietary inadequacies are widespread in the Mongolian population. Mandatory industrial fortification would be a safe and effective means of improving nutrition as part of a larger national nutrition strategy. The country's Household Socio-economic Survey presents a viable platform for surveillance of dietary trends and for informing the design of nutrition programs.

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Chimka, anne, baba, and my family.

I dedicate this work to my grandfather, Ercüment Tahir.

I. Seasonal epidemiology of serum 25-hydroxyvitamin D concentration among healthy adults living in rural and urban areas in Mongolia

Abstract

Many factors put Mongolians at risk of vitamin D deficiency. Despite low levels observed in Mongolian children and pregnant women, there are few data published on the vitamin D status of non-pregnant adults. Between summer 2011 and winter 2013, paired summer and winter blood samples were collected from 320 healthy men and women (20–58 years) living in eight Mongolian provinces. Mean serum 25(OH)D concentrations were 22.5 ng/mL (95% CI: 14.5, 32.5) in summer and 7.7 ng/mL (95% CI: 4.6, 10.8) in winter, with a distribution (<10/10–20/20–30/≥30 ng/mL) of 3.1%/39.3%/39.6%/17.9% in summer and 80.1%/19.5%/0.3%/0.0% in winter. Residents of the capital, Ulaanbaatar, had lower levels in both seasons than any other region, whereas residents of the Gobi desert had the highest. In summer, indoor workers had significantly lower levels than outdoor workers (−2.3 ng/mL; 95% CI: −4.1, −5.7) while levels in males exceeded those in females (4.0 ng/mL; 95% CI: 2.3, 5.7). Effects of region, occupation, and sex were also significant in multivariable regression. In conclusion, Mongolian adults had extremely low serum 25(OH)D, particularly in winter, when 80.1% had concentrations below 10 ng/mL. These results indicate a need for effective vitamin D interventions for the Mongolian adult population, particularly among women and residents of Ulaanbaatar.

Introduction

Most of Mongolia lies north of the 42nd parallel, above which the average daily angle of incident solar radiation is too small to induce appreciable cutaneous synthesis of pre-vitamin D between November and March (1). The fact that most of Mongolia is elevated above 1000 m means that the country's surface temperature remains relatively depressed, especially during winter, because Mongolia is landlocked and is less shielded from extreme variations in climate that would otherwise be tempered by proximity to an ocean (2). Cold weather results in significantly decreased ultraviolet-B (UV-B) exposure in humans because it discourages outdoor activity and encourages wearing more clothing (3). As such, Mongolia's geographic factors have historically combined to expose its population to a high risk of vitamin D deficiency. There also exists a low availability of vitamin D-rich foods in Mongolia, such as fish, and there are currently no vitamin-D fortified foods (4). One local milk producer, Gum, produced vitamin D-fortified milk on a small scale in Ulaanbaatar, but has recently discontinued it. Vitamin D supplementation programs for children have had challenges achieving desired coverage or compliance (5).

A high prevalence of rickets was first reported among Ulaanbaatar children in 1992 (6) (42.4% of children under five years of age having at least one sign). Rickets had become drastically more prevalent in Mongolia following the country's independence in 1990, and the halt of widespread pediatric supplementation programs. It has begun to decline very gradually over the following decade as supplementation programs have been restarted (7). The most recent assessment of rickets and vitamin D status among Mongolian children is found in the nationally-representative Fourth National Nutrition Survey (FNNS) completed in 2010 by the Ministry of Health (5,8). The FNNS found a considerable prevalence of classic rickets symptoms, including cranial deformation (18.3% of all children less than five years old deformed), pectus carinatum (pigeon chest) (9.5%), and genu varum (bow-leggedness) (15.7%). FNNS results from samples collected in September 2010 also revealed that 42.4% of children under five years of age had 25(OH)D serum concentrations below 10 ng/mL.

The vitamin D status of non-pregnant, reproductive age women was also investigated in the FNNS revealing that 52.2% of 867 women surveyed nationwide between July and September had serum 25(OH)D concentrations below 10 ng/mL (5). Previous work from our group showed 79.3% of 420 women in Ulaanbaatar to have levels <10 ng/mL in spring (1). Despite these concerning observations, epidemiologic studies of vitamin D status among Mongolian women have been solely descriptive in nature, and only one has accounted for seasonal variation; data from a study by Uush determined mean 25(OH)D levels in 62 Ulaanbaatar pregnant women during the summer (12.7 ng/mL), fall (11.7 ng/mL), winter (9.7

ng/mL), and spring (7.7 ng/mL) of 2000–2001 (9). No studies have been conducted to determine the vitamin D status of Mongolian men, or to differentiate status between urban and rural areas or indoor and outdoor workers. Although Mongolia has a well-established infrastructure for public health practice and education, research funding is limited and assays for micronutrient analysis are not widely available to the public sector. Thus, data on micronutrient status and intake of Mongolian adults are limited or non-existent. As a consequence, the Ministry of Health lacks the necessary information to inform public policy regarding supplementation and food fortification programs to ensure micronutrient sufficiency throughout the country.

To respond to this dearth of information, the Nationwide Micronutrient Assessment of Mongolian Adults (a.k.a. “Nationwide Study”) was initiated in 2011 as a collaborative effort between the Harvard T.H. Chan School of Public Health, the Mongolian Institute of Medical Sciences, the Mongolian National University of Medical Sciences, and the University of Otago, New Zealand. Our specific objectives were to determine the seasonal status of vitamin D in adult subgroups defined by region, occupation, and sex, and to identify seasonal predictors of vitamin D status. We collected diet and lifestyle questionnaire data and paired summer and winter serum samples from 320 participants across eight regions in Mongolia between 2011 and 2013.

Methods

Study population

The primary determinant of 25(OH)D in Mongolia was assumed to be exposure to UV-B radiation. The sampling frame was designed to maximize contrasts in UV-B exposure by sampling based on the season of assessment, geographic region of residence, indoor vs. outdoor occupation, and sex. Season was expected to be the most important of these variables, given the effects of season on the average daily hours of sunlight exposure, average intensity of UV-B exposure, and percentage of total body surface area exposed outdoors (10). Region was also expected to have pronounced effects on UV-B exposure due to regional variations in latitude, altitude, air pollution, other atmospheric variables, and lifestyle factors (11). Occupation was predicted to have a significant effect due to differences in the amount of average daily UV-B exposure incurred by “indoor” occupations (largely office workers), and “outdoor” occupations (largely nomadic herders). While sex was not expected to inherently affect 25(OH)D levels to a significant extent, it was hypothesized that pronounced differences in UV-B exposure might result from gender-based work patterns, as has been observed in other countries (11).

The regions selected for the study were the capital city of Ulaanbaatar, the southern province of Omnogobi, the north-central province of Bulgan, the northern province of Khuvsgul, the central province of Tuv, the northeastern province of Sukhbaatar, the western province of Khovd, and the eastern province of Dornod (Figure S1.1). Each region was sampled in both the summer and winter seasons between 2011 and 2013. Forty participants were recruited from each region, providing a total of 320 participants. Half of each of the regional groups of participants (n = 20 of 40) were composed of indoor workers (office workers, other white-collar professionals, and factory workers drawn from the urban areas of Ulaanbaatar and the provincial capitals of Dalanzadgad (Omnogobi), Bulgan (Bulgan), Murun (Khuvsgul), Zunmod (Tuv), Baruun Urt (Sukhbaatar), Khovd (Khovd), and Choibalsan (Dornod)). The remaining participants at each site were composed of outdoor workers (outdoor laborers drawn from Ulaanbaatar and herders drawn from the rural areas of Bayandalai (Omnogobi), Archon (Bulgan), Chagall (Khuvsgul), Altanbulag (Tuv), Khalzan (Sukhbaatar), Buyant (Khovd), and Bayantumen (Dornod)). Each group of indoor or outdoor workers included 10 males and 10 females. For each group of ten men or women, the margin of error for estimating the true mean summer or winter 25(OH)D level was estimated to be 5% (12).

The study regions were sampled based on their geographic disparateness. The urban and rural areas within each region were sampled by convenience, and eligible study participants within these areas were randomly sampled from a list of local residents. Eligible study participants were identified and located by local public health officials at each site, approached at their homes or work places, and asked if they would like to join the study. Participants were included in the study if they were 20 to 58 years old, free of acute or chronic health conditions, not pregnant, and able to participate in both summer and winter data collection. Ethical approval was obtained from the Mongolian Ministry of Health Ethical Review Board and the Harvard T.H. Chan School of Public Health Institutional Review Board (Protocol Title: "Nationwide study on Vitamin D and other micronutrients status among Mongolian adults"; Protocol Number: 21002; Submission Number: CR-21002-03). Eligible participants provided written informed consent.

Data collection

Study visits were conducted between the months of June to August and January to March over three consecutive years from 2011 to 2013. Two 8 mL blood samples (winter and summer) were drawn from each participant into four vacutainers. The blood samples were then separated by centrifuge, and the serum was extracted and aliquoted. Serum aliquots were transported to Ulaanbaatar in a portable freezer where they were stored at −25 °C until analysis. Serum 25(OH)D analysis was conducted at the Bayangol Medical Center Clinical Laboratory using the DiaSorin LIAISON method (13), a direct competitive, chemiluminescence immunoassay using directly coated magnetic microparticles. To validate the LIAISON assay for use in this study, the investigators helped Bayangol laboratory to participate in the internationally-recognized Vitamin D External Quality Assessment Scheme (DEQAS) (14). Validity was assessed according to DEQAS criteria throughout multiple validation runs spanning the duration of the study, by calculating the percent difference between our analyzed values of the 25(OH)D concentrations of the 40 DEQAS samples sent to our laboratory and their all-laboratory trimmed mean (ALTM) values assigned by DEQAS. Analyzed concentrations of 34 of the 40 DEQAS samples sent to our laboratory fell within 25% of the ALTM, satisfying the 80% standard required for DEQAS certification. A graphical comparison between the true and analyzed concentration of each sample is presented in Figure S1.2. For 20 of the DEQAS samples, the all-lab trimmed mean was in turn validated against values obtained by National Institute of Standards and Technology (NIST) reference measurement procedures, which yielded an R2 of 0.967 and a mean percent difference of −2.3%.

At the time of each blood collection, study participants were also administered a questionnaire by trained study staff members. As the same participants were sampled in both summer and winter, certain variables were assessed only in the summer as these variables were assumed to remain approximately constant throughout the six months between data collection periods. Variables assessed only once included each participant's occupation, worksite, ethnicity, age, highest level of education attained, type of housing, and self-reported height and weight. Variables assessed in both summer and winter included the frequency of consumption of eggs, organ meats, and fish, use of supplements, sunscreen, a brimmed hat, and makeup, occurrence of sunburn, and source of milk and culinary flour (as locally-produced milk and flour are being considered as potential vehicles for vitamin D fortification in Mongolia). In addition, sun exposure defined as more or less than 30 min over five time periods of the day (9:00 to 11:00, 11:00 to 14:00, 14:00 to 16:00, 16:00 to 18:00, and after 18:00) in eight areas of the body (face, neck, torso, upper arms, lower arms, hands, upper legs, and lower legs) were assessed on separate week and weekend days.

Data variables

Body mass index (BMI) (kg/m2) was derived using each participant's self-reported height and weight. Categorical variables of fish consumption, use of supplements, sunscreen, a brimmed hat, and makeup, occurrence of sunburn, and flour type were condensed into binary variables for use in regression models, and highest level education attained was also converted to a continuous variable of years of education attained based on the structure of the Mongolian education system. Total dietary intake of vitamin D (in international units (IU)/day) from eggs, organ meats, and fish was calculated using food composition data (15,16).

In summer and winter, the percent of body surface area (% BSA) typically exposed to the sun was calculated by summing the % BSA of each body part derived from a Lund-Browder chart (17) (a clinical tool for assessing burn severity) which was modified using more precise estimates of body part surface area from 3-D whole-body scans in the Taiwanese Bodybank (18). A separate exposure duration score was calculated by summing up respondents' periods of the day typically exposed, in which weekdays and weekends were weighted in a 5:2 ratio, "more than 30 min exposed" and "less than 30 min exposed" in a particular period of the day were weighted in a 2:1 ratio, and only exposure periods from 11:00 to 14:00 and 14:00 to 16:00 were considered as contributive to vitamin D status (we determined that incident radiation is not intense enough to induce vitamin D synthesis in Mongolia in the summertime during any other periods of the day using data from the Tropospheric Ultraviolet and Visible (TUV) Model (19). Values of the score range from 0 (indicating no appreciable sun exposure) to 28 (indicating more than 30 min of exposure during both 11:00 to 14:00 and 14:00 to 16:00 on both weekdays and weekdays), where a 1 unit increase in score can be interpreted as the effect of increasing one's exposure during either 11:00 to 14:00 or 14:00 to 16:00 from either "none" to "less than 30 min exposed" or from "less than 30 min" to "more than 30 min" on a single day of the week.

Statistical analysis

Univariate analyses were conducted to describe the characteristics of participants, examine variable distributions, and detect missing values. The mean summer and winter serum 25(OH)D concentrations were calculated for subgroups of the study population according to the sampling scheme of season, region, occupation, and sex. The proportion of different subgroups' subjects falling within different ranges of serum 25(OH)D concentrations (<10 ng/mL, 10 to <20 ng/mL, 20 to <30 ng/mL, and >30 ng/mL (20)) were also calculated. Data for two outlying participants in summer and one in winter were excluded from analyses (>50 ng/mL in summer or >25 ng/mL in winter). LIAISON measurements for one subject in summer and 12 subjects in winter fell short of the assay's minimal detection limit of 4 ng/mL; in statistical analyses, these measurements were rounded to 3.9 ng/mL. Sensitivity analyses including excluded or rounded values did not materially affect results.

Within each season, differences in non-seasonal population characteristics between indoor and outdoor participants, and in seasonal variables between indoor and outdoor workers were compared using independent samples t-tests for continuous variables and chi-square tests for categorical variables (Fisher's exact tests were used for categorical variables in which any cell counts were smaller than 5). A paired samples t-test was used to assess the difference in the mean 25(OH)D concentration between seasons. Within each season, differences in 25(OH)D levels between regions, and between occupation-sex groups, were assessed using ANOVA and Tukey-Kramer adjustment for multiple comparisons. Also within each season, independent samples t-tests were used to assess differences between indoor and outdoor workers across all regions, males and all females across all regions, indoor and outdoor workers within each region, and males and females within each of the 16 region-occupation groups.

In each season, measured serum 25(OH)D concentration was modeled as a linear function of each predictor in simple linear regression to identify significant risk factors for vitamin D deficiency. To improve the normality of residuals in the models, 25(OH)D concentrations were transformed by the natural logarithm. Parameter estimates and 95% confidence limits from the log-normal models were back-transformed to the original scale using the formula $\%\Delta Y = (e\beta\text{-}1) \times 100$, in which $\%\Delta Y$ represents the expected percent difference in 25(OH)D associated with a one-unit change in β (21). The following three multiple regression models were run for each season in order to identify independent predictors of vitamin D status within each season: seasonal vitamin D serum concentration as a function of (1) age and sex; (2) age, sex, region, and occupation; and (3) age, sex, region, occupation, and any other statistically significant predictors of vitamin D status or apparent confounders of the association between age, sex, region, or occupation on vitamin D status. To improve interpretability of parameter estimates across seasons, the same (or seasonal-equivalent of) variables were used in both summer and winter models. Missing values in multiple regression were modeled using missing indicators in order to minimize the amount of statistical information lost.

Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Alpha of 0.05 was used to determine significance of all statistical tests. Results are generally expressed as means ± standard deviations (SDs), or percentages.

Results

Non-seasonal demographic characteristics of the study population stratified by occupation are presented in Table 1.1. Overall, the study population was predominantly of Khalkh descent (82%), the ethnic majority of Mongolia. Participants were generally middle-aged (39.0 ± 9.7 years) ranging from 20 to 58 years old. On average, participants had completed 12.5 ± 3.8 years of education, with 12 years corresponding to the completion of high school in Mongolia. Outdoor occupation participants lived primarily in yurts (83%) and houses without central heating (14%), and indoor participants were more loosely distributed across different housing types. Indoor participants were primarily office workers (90%) and outdoor participants were mostly professional herders (86%) and urban or peri-urban outdoor laborers (13%). Table 1.2 presents participant characteristics that vary by season. Sunburn was more common in summer (80%) than in winter (50%), and use of a brimmed hat was more common in winter (70%) than summer (58%) among indoor participants. Vitamin D-containing supplement use did not vary between summer (19%) and winter (20%); only seven participants reported using vitamin D-containing supplements in any season. Most participants exclusively used Mongolian flour in their cooking (84% in summer and 72% in winter). The mean daily vitamin D intake from foods was less than 70 IU in any season.

Table 1.1: Non-seasonal characteristics of study population

Characteristic	**Occupation**		***p***
	Indoor (*n* = 160)	**Outdoor (*n* = 160)**	
Female sex	80 (50)	80 (50)	1.00
Ethnicity			0.021
Khalkh	125 (88)	96 (75)	
Zakhchin	13 (9)	24 (19)	
Other	4 (3)	8 (6)	
Age, years	37.5 ± 9.9	40.3 ± 9.3	0.011
BMI, kg/m^2	26.0 ± 4.2	25.1 ± 3.7	0.031
Education, years	14.8 ± 2.2	10.1 ± 3.6	<0.001
Housing			<0.001
Yurt	24 (17)	106 (83)	
Apartment	39 (28)	4 (3)	
House (central heating)	40 (29)	4 (3)	
House (no central heating)	37 (26)	14 (11)	
Worksite			<0.001
Outdoor labor	1 (1)	20 (13)	
Office	143 (90)	2 (1)	
Herder	0 (0)	138 (86)	
Factory	6 (4)	0 (0)	
Other	9 (6)	0 (0)	

Values are *n* (%) or means ± SDs. Percentages are calculated after excluding missing values. Extent of missingness: ethnicity (16%), age (5%), body mass index (BMI) (6%), education (16%), housing (16%), worksite (<1%). *p* values are drawn from tests of differences between occupations within the same seasons.

Table 1.2: Seasonal characteristics of study population

Characteristic	Season and Occupation					
	Summer (*n* = 160)			Winter (*n* = 160)		
	Indoor (*n* = 80)	Outdoor (*n* = 80)	*p*	Indoor (*n* = 80)	Outdoor (*n* = 80)	*p*
Serum [25(OH)D], ng/mL	21.3 ± 8.5	23.6 ± 7.2	0.010	7.6 ± 3.2	7.9 ± 3.0	0.52
Body surface area exposed, %	32.9 ± 14.5	33.0 ± 14.4	0.94	17.4 ± 12.2	14.9 ± 8.7	0.045
Exposure duration score [1]	11.1 ± 8.2	23.9 ± 6.8	<0.001	11.9 ± 7.2	17.8 ± 9.9	<0.001
Sun-exposure behaviors [2]						
Used a brimmed hat	83 (58)	102 (81)	<0.001	101 (70)	119 (77)	0.16
Used sunscreen	27 (24)	15 (16)	0.14	15 (21)	13 (16)	0.46
Used makeup [3]	54 (77)	37 (63)	0.07	57 (76)	48 (62)	0.05
Experienced sunburn	115 (81)	95 (78)	0.53	71 (54)	70 (47)	0.23
At least 100 IU/day of vitamin D from [4]						
Fish	1 (1)	0 (0)	1.00	0 (0)	0 (0)	0.28
Eggs	0 (0)	1 (1)	0.08	2 (3)	0 (0)	1.00
Organ meats	0 (0)	0 (0)	1.00	0 (0)	0 (0)	1.00
Total IU/day from fish, eggs, organs [4]	24.5 ± 30.6	15.4 ± 28.8	0.41	33.1 ± 37.2	17.5 ± 23.7	0.015
Supplement use [2]			<0.001			0.36
Multivitamin	15 (13)	0 (0)		9 (6)	7 (6)	
Vitamin D	1 (1)	0 (0)		5 (4)	1 (1)	
Other or unspecified	13 (11)	17 (14)		13 (9)	17 (14)	
None	89 (75)	103 (86)		113 (81)	100 (80)	
Milk consumption, cups/day [5]						
Manufactured milk, Mongolian	0.4 ± 0.4	0.8 ± 0.8	0.003	0.4 ± 0.6	0.4 ± 0.5	0.91
Manufactured milk, imported	0.1 ± 0.2	0.1 ± 0.2	0.27	0.0 ± 0.0	0.0 ± 0.1	0.48
Fresh cow milk	0.5 ± 0.4	1.4 ± 0.6	<0.001	0.3 ± 0.5	0.7 ± 0.6	<0.001
Source of cooking flour			0.39			0.65
Always Mongolian	46 (79)	53 (88)		58 (70)	51 (75)	
Mostly Mongolian	7 (12)	4 (7)		15 (18)	11 (16)	
Half Mongolian, half imported	4 (7)	2 (3)		8 (10)	5 (7)	
Mostly imported	1 (2)	0 (0)		0 (0)	1 (1)	
Always imported	0 (0)	1 (2)		2 (2)	0 (0)	

Values are *n* (%) or means ± SDs. Percentages are calculated after excluding missing values. *p* values are drawn from tests of differences between occupations within the same seasons. [1] Range of exposure duration score: 0 to 28; [2] Sun-exposure behaviors and supplement use are assessed as "Ever during past six months"; [3] Makeup use assessed in females only; [4] IU: international unit; [5] Cup volume: 240 mL.

The mean serum 25(OH)D concentration in Mongolian adults was 7.7 ± 3.1 ng/mL in winter and 22.5 ± 8.0 ng/mL in summer (difference of −14.9 ng/mL; 95% CI: −15.7, −14.1; $p < 0.001$) (Table S1.1). Only three participants' winter serum 25(OH)D concentrations exceeded their summer concentrations. Vitamin D levels were unavailable for 12 participants in winter; the mean of the summer values for these 12 individuals was not significantly different from that of the rest of the group ($p = 0.16$). The correlation between summer and winter 25(OH)D values was 0.48. Residents of Ulaanbaatar exhibited a lower mean serum 25(OH)D concentration than those of any other region in summer (17.3 ± 6.7 ng/mL) and winter (5.4 ± 1.3 ng/mL), whereas those of Omnogobi exhibited the highest (27.7 ± 8.1 ng/mL in summer and 9.6 ± 3.7 ng/mL in winter) (Figure 1.1, Table S1.1), although only certain regional comparisons with Ulaanbaatar and Omnogobi were statistically significant (Table S1.2). In summer, indoor workers exhibited significantly lower serum concentrations than outdoor workers (−2.3 ng/mL; 95% CI: −4.1, −5.7; $p = 0.010$) and concentrations in males exceeded those in females (4.0 ng/mL; 95% CI: 2.3, 5.7; $p < 0.001$) (Figure 1.2, Table S1.1); differences between occupations or between males and females were not significant in winter. The proportion of subjects categorized according to different ranges of serum 25(OH)D concentrations are shown in Figure 1.3.

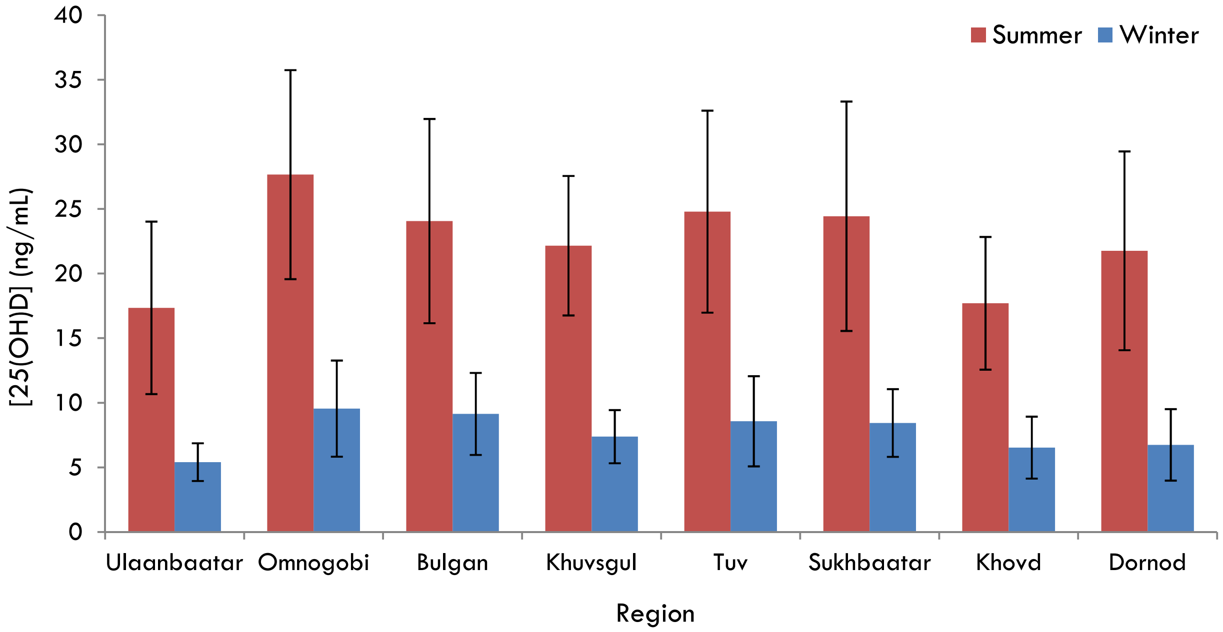

Figure 1.1: Mean (standard deviation, SD) serum 25(OH)D concentration by season and region. Bars indicate mean measured 25(OH)D concentrations (ng/mL) in summer (red bars) and winter (blue bars) ± SDs, summer *n* = 318, winter *n* = 307. *p* values for regional differences are provided in Table S1.2.

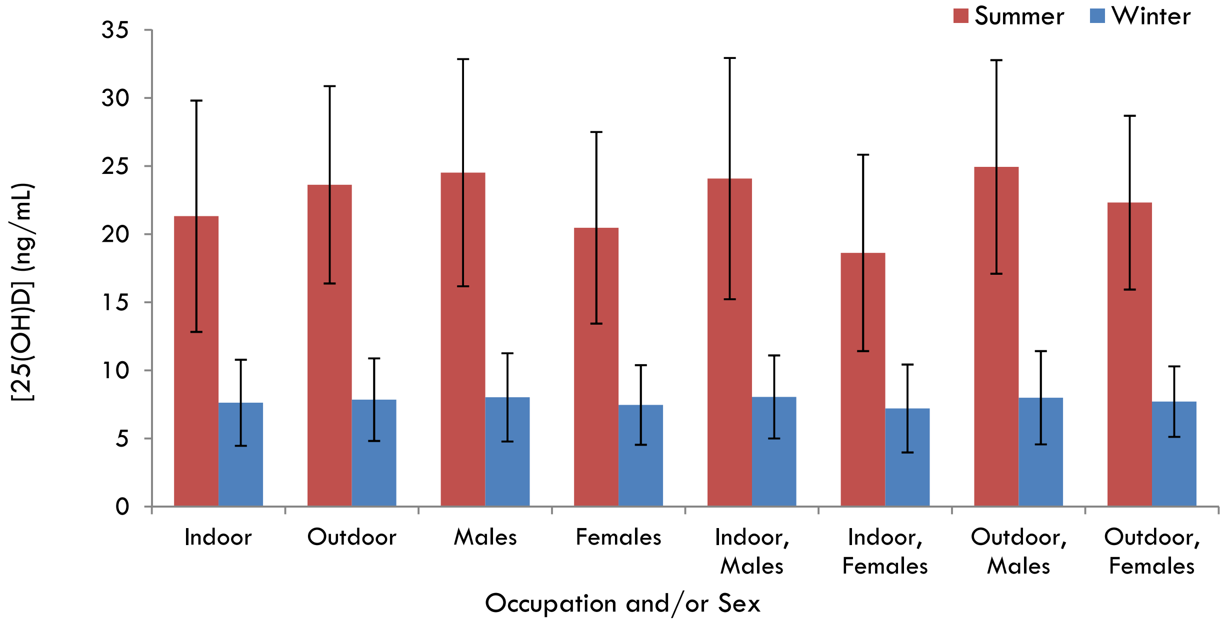

Figure 1.2: Mean (SD) serum 25(OH)D concentration by season, occupation, and sex. Bars indicate mean measured 25(OH)D concentrations (ng/mL) in summer (red bars) and winter (blue bars) ± SDs, summer *n* = 318, winter *n* = 307. Summer: Indoor < Outdoor, Males > Females, Indoor, Females < Indoor, Males = Outdoor, Males = Outdoor, Females, *p* < 0.05. Winter: Indoor = Outdoor, Males = Females, Indoor, Males = Indoor, Females = Outdoor, Males = Outdoor, Females, *p* < 0.05.

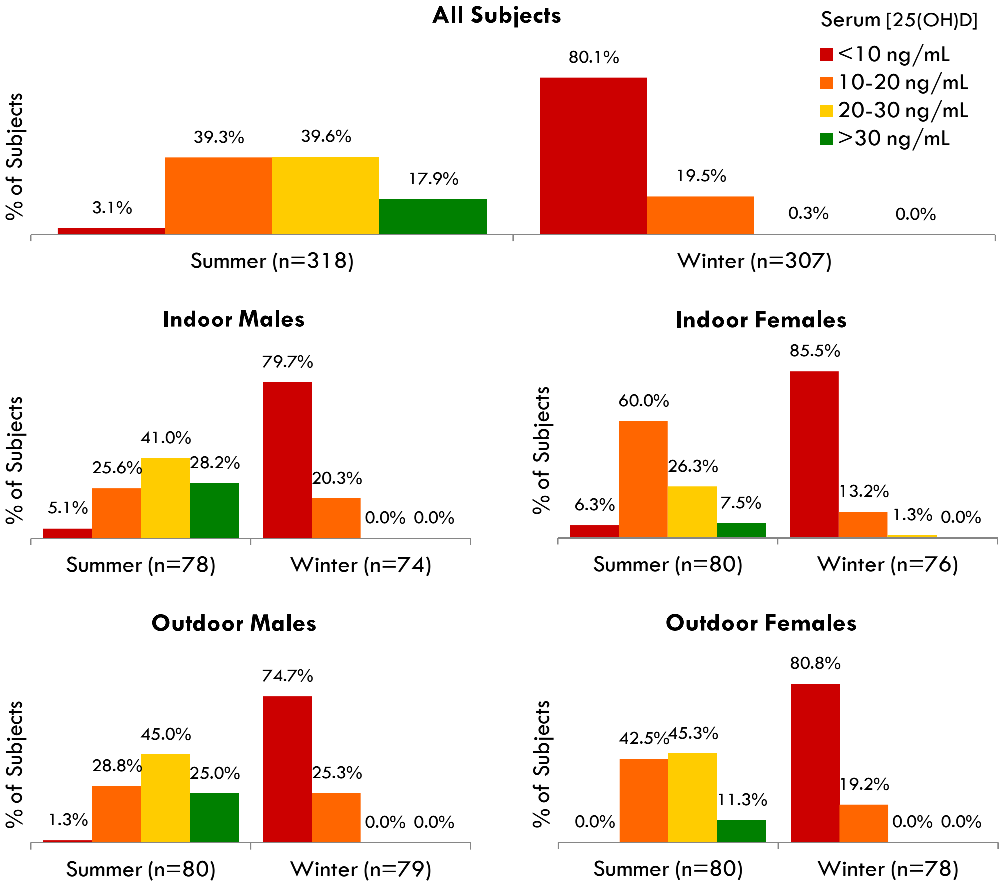

Figure 1.3: Prevalence of serum 25(OH)D concentration categories according to season, occupation, and sex subgroups (red: <10 ng/mL, orange: 10 to 20 ng/mL, gold: 20 to 30 ng/mL, green: >30 ng/mL).

We next assessed differences in seasonal 25(OH)D levels between occupation groups within regions, and between males and females within regional occupation groups. Within regions, indoor workers had lower summer 25(OH)D concentrations than outdoor workers in six of eight regions, with statistically significant differences found in Sukhbaatar (−9.7 ng/mL; 95% CI: −14.5 to −4.9; $p < 0.001$) and Khovd (−5.2 ng/mL; 95% CI: −8.0, −2.3; $p < 0.001$) (Table S1.1); Sukhbaatar indoor workers also had significantly lower levels than herders in winter (−1.7 ng/mL; 95% CI: −3.4, −0.1; $p = 0.042$). With the exception of outdoor workers in Ulaanbaatar, the serum concentrations of males within every regional occupation group exceeded those of females in the summer (Table S1.1), though this difference was only statistically significant for Tuv indoor workers (8.3 ng/mL; 95% CI: 0.8, 15.7; $p = 0.032$); such a pattern was not observed in the winter.

Results of bivariate and multivariable regression models are summarized in Tables 1.3 and 1.4, respectively, in which β is interpreted as the expected percent change in 25(OH)D levels in response to a one unit increase in a continuous parameter or a one level increase in a categorical parameter, holding other parameters constant. Consistent with the low intake and modest content of vitamin D naturally found in food, consumption of fish, liver, or eggs did not predict 25(OH)D levels in summer or winter, despite these being the best natural dietary sources of vitamin D in Mongolia. Supplement use was not associated with higher 25(OH)D levels in multivariable models, although models lacked statistical power, as supplement use was rare. Multivariable-adjusted results showed summer 25(OH)D levels were independently related to younger age, male sex, outdoor occupation, and residence outside Ulaanbaatar (except in Khovd). Although statistically significant, greater body surface exposure and less exposure duration had a clinically small impact on 25(OH)D levels (5.9% increase in 25(OH)D for a 1 SD increase in %BSA, and a −5.5% decrease with a 1 SD increase in duration of exposure). In winter, 25(OH)D levels were higher among younger individuals, men, and those residing outside of Ulaanbaatar, but other variables did not predict 25(OH)D levels.

Table 1.3: Unadjusted percent difference in 25(OH)D concentration by exposure to demographic and seasonal factors

Parameter	Season			
	Summer (*n* = 318) [1]		Winter (*n* = 307) [1]	
	%ΔY (95%CI)	*p*	%ΔY (95%CI)	*p*
Region				
Ulaanbaatar	ref (16.2 ng/mL)	<0.001	ref (5.2 ng/mL)	<0.001
Omnogobi	63 (41, 89)	<0.001	69 (47, 95)	<0.001
Bulgan	41 (22, 63)	<0.001	65 (44, 90)	<0.001
Khuvsgul	33 (15, 54)	<0.001	36 (18, 56)	<0.001
Tuv	46 (26, 70)	<0.001	54 (34, 77)	<0.001
Sukhbaatar	39 (20, 62)	<0.001	54 (33, 77)	<0.001
Khovd	5 (−9, 21)	0.53	18 (2, 36)	0.03
Dornod	26 (9, 46)	<0.001	20 (4, 38)	0.01
Occupation				
Indoor	ref (17.1 ng/mL)	<0.001	ref (6.9 ng/mL)	<0.001
Outdoor	15 (6, 25)	<0.001	3 (−5, 12)	0.46
Sex				
Male	ref (27.5 ng/mL)	<0.001	ref (7.9 ng/mL)	<0.001
Female	−16 (−23, −9)	<0.001	−6 (−13, 2)	0.13
Age, years	−1 (−1, 0)	<0.001	−0 (−1, 0)	0.06
Ethnicity				
Khalkh	ref (21.6 ng/mL)	<.001	ref (7.5 ng/mL)	<0.001
Non-Khalkh	−0 (−11, 12)	0.98	−3 (−13, 8)	0.55
BMI, kg/m^2 [1]	−1 (−2, 0)	0.17	1 (0, 2)	0.15
Education level				
Secondary school or less	ref (22.4 ng/mL)	<0.001	ref (7.4 ng/mL)	<0.001
High school	4 (−7, 17)	0.46	6 (−6, 19)	0.36
University or professional certification	−9 (−19, 1)	0.06	−3 (−13, 8)	0.56
Housing type				
Apartment	ref (18.6 ng/mL)	<0.001	ref (7.3 ng/mL)	<0.001
Yurt	29 (14, 45)	<0.001	8 (−4, 22)	0.20
House with central heating	5 (−9, 21)	0.52	−9 (−22, 5)	0.21
House without central heating	11 (−4, 27)	0.17	−5 (−18, 10)	0.49
Sun-exposure [2]				
% body surface area exposed, 1 SD [3]	5.3 (1, 10)	0.01	−1 (−5, 3)	0.70
Exposure duration score, 1 SD [3]	4.7 (0, 9)	0.05	2 (−2, 6)	0.40
Used a brimmed hat	10 (0, 21)	0.04	−10 (−18, −1)	0.04
Used sunscreen	−12 (−22, 0)	0.06	−3 (−17, 14)	0.75
Used makeup [4]	−7 (−18, 5)	0.24	−6 (−17, 6)	0.30
Experienced sunburn	2 (−8, 14)	0.73	−4 (−12, 5)	0.36
Diet and supplements				
Any fish consumption [2]	−5 (−17, 9)	0.49	−9 (−22, 8)	0.28
Portions/day of liver or organ meats	−11 (−47, 49)	0.65	−2 (−22, 25)	0.90
Number of eggs per day	−14 (−30, 6)	0.16	4 (−15, 28)	0.72
IU/day from fish, eggs, organs [5]	0 (0, 0)	0.34	0 (0, 0)	0.93
Used multivitamins or vitamin D [2]	19 (−1, 43)	0.06	1 (−13, 18)	0.89

%ΔY for continuous parameters is interpreted as the % difference in seasonal 25(OH)D concentration associated with a one-unit increase in the parameter. %ΔY for levels of categorical variables are interpreted as the % change in seasonal 25(OH)D concentration associated with each level of the parameter. *p*-values are those associated with the difference in log([25(OH)D]) for a one-unit change in a continuous parameter, a level of a categorical parameter relative to the reference category (ref), or the reference category itself. Reference category values are obtained from the model intercepts. [1] In summer, two vitamin D outliers were excluded (*n* = 318), and in winter, one vitamin D outlier was excluded and 12 vitamin D measurements were missing (*n* = 307); [2] Sun-exposure behaviors, supplement use, and fish consumption are assessed as "Ever during past six months". %ΔY for these parameters is expressed in comparison to the reference group "never"; [3] %ΔY for % body surface area exposed and exposure duration score are expressed in terms of a 1 SD change in the parameter; [4] Makeup use assessed in females only; [5] IU: international unit.

Table 1.4: Multivariable adjusted percent differences in 25(OH)D concentration by exposure to demographic and seasonal factors.

Parameter	Season			
	Summer (*n* = 318) [1]		Winter (*n* = 307) [1]	
	%ΔY (95%CI) or Intercept	*p*	%ΔY (95%CI) or Intercept	*p*
Model 1				
Intercept	36 ng/mL	<0.001	9 ng/mL	<0.001
Age, years	−1 (−1, 0)	<0.001	−0 (−1, 0)	0.07
Female sex	−15 (−22, −9)	<0.001	-6 (-13, 2)	0.16
Model 2				
Intercept	23 ng/mL	<0.001	6 ng/mL	<0.001
Age, years	−1 (−1, −1)	<0.001	−1 (−1, 0)	<0.01
Female sex	−15 (−21, −10)	<0.001	−5 (−11, 2)	0.16
Region				
Ulaanbaatar	ref		ref	
Omnogobi	64 (44, 88)	<0.001	69 (47, 94)	<0.001
Bulgan	45 (27, 67)	<0.001	69 (47, 94)	<0.001
Khuvsgul	36 (18, 55)	<0.001	37 (19, 57)	<0.001
Tuv	49 (30, 70)	<.001	55 (35, 78)	<0.001
Sukhbaatar	45 (26, 66)	<0.001	56 (35, 79)	<0.001
Khovd	6 (−7, 22)	0.37	19 (3, 37)	0.02
Dornod	31 (15, 50)	<0.001	22 (6, 40)	<0.01
Outdoor occupation (vs. indoor)	17 (10, 26)	<0.001	4 (−3, 12)	0.24
Model 3				
Intercept	19 ng/mL	<0.001	5 ng/mL	<0.001
Age, years	−1 (−1, 0)	<0.001	0 (−1, 0)	<0.01
Female sex	−17 (−22, −11)	<0.001	−7 (−13, 0)	0.06
Region				
Ulaanbaatar	ref		ref	
Omnogobi	68 (45, 95)	<0.001	79 (53, 111)	<0.001
Bulgan	49 (27, 75)	<0.001	76 (53, 107)	<0.001
Khuvsgul	34 (17, 54)	<0.001	42 (25, 68)	<0.001
Tuv	54 (33, 78)	<.001	66 (43, 98)	<0.001
Sukhbaatar	39 (20, 62)	<.001	60 (40, 92)	<0.001
Khovd	9 (−7, 29)	0.29	31 (10, 59)	<0.01
Dornod	35 (14, 60)	<0.001	33 (13, 64)	<0.01
Outdoor occupation (vs. indoor)	23 (11, 35)	<0.001	7 (−2, 19)	0.11
% body surface area exposed, 1 SD [2]	6 (2, 10)	<0.01	−0 (−4, 4)	0.95
Exposure duration score, per 1 SD [2]	−6 (−11, 0)	0.04	1 (−3, 5)	0.71
Housing type				
Apartment	ref		ref	
Yurt	7 (−6, 21)	0.32	−9 (−21, 3)	0.12
House with central heating	4 (−9, 18)	0.61	−10 (−22, 3)	0.11
House without central heating	13 (−1, 29)	0.06	1 (−13, 14)	0.99

%ΔY for continuous parameters is interpreted as the % difference in seasonal 25(OH)D concentration associated with a one-unit increase in the parameter. %ΔY for levels of categorical variables are interpreted as the % change in seasonal 25(OH)D concentration associated with each level of the parameter. *p*-values are those associated with the difference in log([25(OH)D]) for a one-unit change in a continuous parameter, a level of a categorical parameter relative to the reference category ("ref"), or the reference category itself. [1] In summer, two vitamin D outliers were excluded (*n* = 318), and in winter, one vitamin D outlier was excluded and 12 vitamin D measurements were missing (*n* = 307); [2] %ΔY for % body surface area exposed and exposure duration score are expressed in terms of a 1 SD change in the parameter.

Discussion

The present study indicates that Mongolian adults had extremely low vitamin D levels, particularly over the winter months, among office workers, and among women. We also observed significant regional variation in 25(OH)D levels, with the lowest concentrations in Ulaanbaatar and the highest in the Omnogobi region, in both winter and summer. This agrees with the latitude and climate of the Gobi desert and their resultant influence on the intensity and frequency of sun-exposure, respectively. Lower vitamin D status in Ulaanbaatar may be related to the fact that Ulaanbaatar suspended the second-highest annual average concentration of PM10 particulate matter pollution of all cities in the world in 2008 (22). Air pollution has been associated with hypovitaminosis D in other parts of the world (23). Ulaanbaatar residents may spend much more time indoors than those in less urbanized or rural areas. The fact that outdoor work was predictive of vitamin D status in both unadjusted and adjusted analyses is likely partly due to the fact that herders spend a large amount of time outdoors. However, this finding also remained after controlling for %BSA and exposure duration score, so it is difficult to attribute the beneficial association seen in herders to differences in sun-exposure behaviors alone.

From a nationally-representative sample of non-pregnant, 15–49 years old women surveyed from July to September, the Fourth National Nutrition Survey (FNNS) estimated the prevalence of vitamin D deficiency (serum 25(OH)D concentration <7.2 ng/mL) and low vitamin D reserve (7.2 to 9.6 ng/mL) to be 30.0% and 22.2%, respectively (5). If our data are reanalyzed using the same categories as the FNNS, we estimate the summer/winter prevalence of vitamin D deficiency and low vitamin D reserve among women in our sample to be 0.6%/55.2% and 1.9%/27.3%, respectively. Our results are not immediately comparable with those of the FNNS for several reasons, including major differences in vitamin D assays, age distributions, sample frames, and seasons of measurement. Given that the FNNS' deficiency and low reserve estimates lie between the corresponding summer and winter estimates of our study, it is possible that had the FNNS been conducted from June to August and January to March, estimates more comparable to those of our study would have been obtained. In both the FNNS and in reanalysis of our data using the FNNS definitions of deficiency and low reserve, no significant differences were found in the prevalence of either indicator between urban and rural women or across 10 years age categories. However, treatment of vitamin D status and age as continuous variables in our study has revealed significant effects of both urban/rural designation and age in both bivariate and multivariable analysis. The negative effect of age on vitamin D status is likely mostly attributable to changes in daily activity patterns and time spent outdoors as one grows older, but may also partly reflect reduced endogenous conversion of cholecalciferol to 25(OH)D (11). The negative association with female sex has also been observed in other studies and may indicate a combination of biological and behavioral differences between men and women (11). Other studies have observed a negative effect of BMI on vitamin D status, which may indicate greater sequestration of vitamin D in the adipose tissue of fatter individuals (10), however this was not observed in this population. Independent associations were also not found between vitamin D status and dietary intake of vitamin D-containing foods, or categorical sun exposure metrics such as sunburn and use of sunscreen, a brimmed hat, or makeup, though these variables have been implicated as predictors in other studies. The null effect of dietary intake on 25(OH)D levels reflects both the lack of vitamin D rich foods and their infrequent consumption. Total vitamin D intake from eggs, organ meats, and fish, at 20–40 IU daily, was far too low to impact circulating 25(OH)D levels; without fortification, it would likely be impractical to rely on dietary modification alone to improve population status in Mongolia. For reference, a scrambled egg, slice of beef liver, and half tin of oily fish (such as sprats) contain approximately 40, 33, and 200 IU of vitamin D, respectively.

One of the strengths of the study was the within-person seasonal assessment of vitamin D status together with the near-complete follow up. Ninety-six percent of participants sampled in summer were also sampled during the following winter. This is remarkable given the difficulty in relocating some of the herders in winter, as many of them had moved from their original locations, as well as the logistic difficulties posed by snow in the rural areas. By measuring vitamin D status of the same individuals in summer and winter, the estimated difference in summer and winter mean 25(OH)D levels within each subgroup of the population is not affected by between-subject variation. Another important strength is the use of a reference method for vitamin D assessment in a limited-resource setting. The participation of the laboratory in DEQAS ensures the analytical reliability of 25(OH)D assay and constitutes an important step forward in local capacity for epidemiologic assessment of vitamin D status in Mongolia. The study also benefits from the use of an anthropometrically-validated method for determining %BSA.

Although a larger sample size might have identified predictors of even more subtle differences in 25(OH)D levels, the current sample allowed the detection of differences in 25(OH)D levels as small as 1% (for one year of age), which represents a difference between 10 ng/mL and 10.1 ng/mL or 30 ng/mL and 30.3 ng/mL. In terms of study design, sampling in winter and summer provided data during periods of extreme sun exposure. However, future studies are warranted to further characterize vitamin D status in spring and fall. Sampling during periods of extreme sun exposure has also not necessarily provided the maximum range of serum 25(OH)D status expected in this population as the concentration of circulating 25(OH)D does not equilibrate until about eight weeks after sun-exposure (24); thus, peak 25(OH)D levels might occur just prior to fall, and nadir just prior to spring. Additionally, while %BSA exposed was positively associated with vitamin D levels in summer, it was negatively associated in winter. The winter finding is likely the result of chance. UV monitoring may have provided more accurate measurements of sun-exposure duration, however our research also corroborates a need for more sensitive sun-exposure questionnaires, which may be less expensively administered in epidemiologic studies but which have as yet rarely succeeded in capturing more than 40% of variation in vitamin D status in other populations (25).

Vitamin D status in Mongolia may be improved in a number of ways. Sun exposure should be encouraged to reduce the likelihood of deficiency during summer, however it is unlikely that either increased sun exposure nor consumption of foods naturally rich in vitamin D will be sufficient to ensure adequacy for most of the population. This is particularly true for the winter months, during which fortification may be necessary. At the moment, the only example of universal fortification in Mongolia is that of salt with iodine. Given Mongolia's highly centralized wheat flour production system (10 mills process approximately 90% of the country's domestically-produced flour (26)), the high consumption of wheat flour products, and the observed predominance of Mongolian flour versus imported flour, vitamin D fortification of wheat may be a sustainable, long-term strategy for improving vitamin D status in the general population. Wheat flour may also be simultaneously fortified with other nutrients shown to be deficient in the population, such as folic acid (a pilot study among 40 women and 80 children in Mongolia demonstrated effectiveness of wheat flour fortification in raising plasma folic acid levels in both women and children (27)). Industrial fortification of wheat flour may be effectively combined with fortification of commercially-produced milk (consumption of which was also greater than that of imported milk) and increased supplementation of groups at particular risk, including women and children.

Conclusion

Vitamin D status was extremely low among Mongolian working-age adults, particularly in winter, during which 80.1% had concentrations below 10 ng/mL. These results indicate the need for both improved screening and intervention in this population, and research should continue to evaluate the efficacy of vitamin D supplementation, fortification, and dietary modification in Mongolia.

Acknowledgments

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Appendix

Appendix A: Supplemental Figures

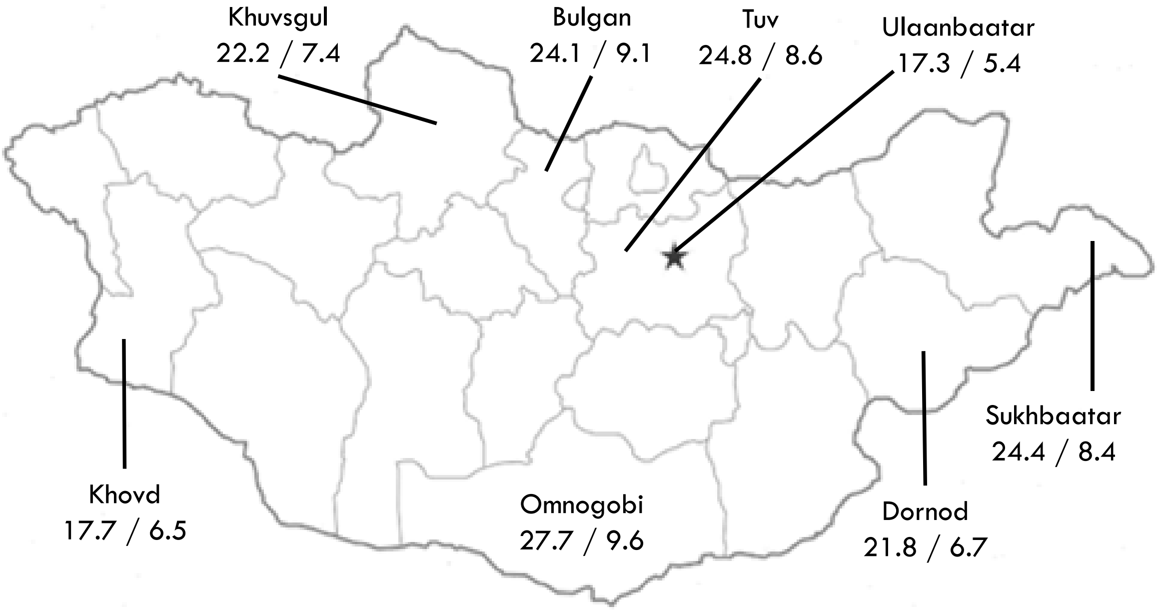

Figure S1.1: Map of Mongolia with study regions indicated. Values below the name of each region indicate the mean measured 25(OH)D concentrations (ng/mL) in summer/winter, summer *n* = 318, winter *n* = 307.

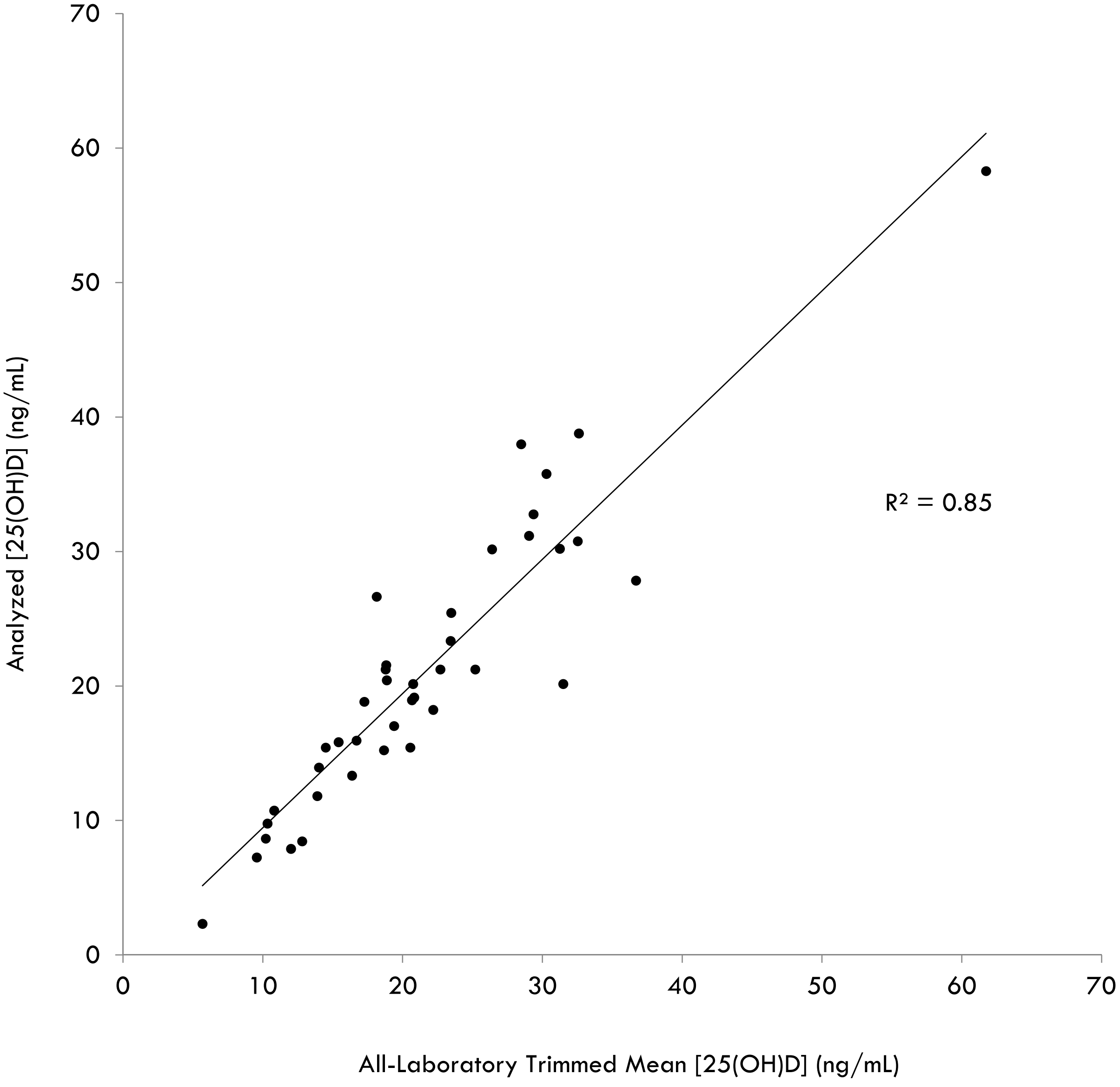

Figure S1.2: DEQAS validation of DiaSorin LIAISON assay (comparison of 40 analyzed values measured using DiaSorin LIAISON with DEQAS all-laboratory trimmed means for the same 40 samples).

Appendix B: Supplemental Tables

Table S1.1: Mean (±SD) serum 25(OH)D concentration by season, region, occupation, and sex

Season [1]	Region [2]	Occupation [3]	Sex [4]	Season [1]	Region [2]	Occupation [3]	Sex [4]
Summer 22.5 ± 8.0	Ulaanbaatar 17.3 ± 6.7	Indoor 16.4 ± 8.3	Male 19.7 ± 9.9	Winter 7.7 ± 3.1	Ulaanbaatar 5.4 ± 1.5	Indoor 5.4 ± 1.3	Male 5.7 ± 1.4
			Female 13.1 ± 5.0				Female 5.1 ± 1.0
		Outdoor 18.3 ± 4.5	Male 17.5 ± 3.3			Outdoor 5.4 ± 1.7	Male 5.4 ± 1.8
			Female 19.1 ± 5.5				Female 5.5 ± 1.6
	Omnogobi 27.7 ± 8.1	Indoor 29.7 ± 7.6	Male 32.5 ± 6.2		Omnogobi 9.6 ± 3.7	Indoor 10.3 ± 3.5	Male * 12.2 ± 3.2
			Female 26.9 ± 8.1				Female 8.4 ± 2.8
		Outdoor 25.6 ± 8.3	Male 29.1 ± 8.9			Outdoor 8.8 ± 3.9	Male * 11.0 ± 4.3
			Female 22.1±6.2				Female 6.6± 1.8
	Bulgan 24.1 ± 7.9	Indoor 23.8 ± 7.7	Male 25.5 ± 6.1		Bulgan 9.1 ± 3.2	Indoor 8.7 ± 3.0	Male 8.7 ± 2.8
			Female 22.3 ± 8.9				Female 8.8 ± 3.3
		Outdoor 24.3 ± 8.3	Male 26.4 ± 7.8			Outdoor 9.5 ± 3.4	Male 10.8 ± 3.7
			Female 22.2 ± 8.6				Female 8.2 ± 2.5
	Khuvsgul 22.2 ± 5.4	Indoor 23.1 ± 6.5	Male * 27.0 ± 6.5		Khuvsgul 7.4 ± 2.1	Indoor 7.5 ± 1.6	Male 7.7 ± 2.0
			Female 19.7 ± 4.4				Female 7.3 ± 1.1
		Outdoor 21.3 ± 4.0	Male 21.3 ± 4.0			Outdoor 7.3 ± 2.4	Male 7.2 ± 2.5
			Female 21.2 ± 4.2				Female 7.3 ± 2.5
	Tuv 24.8 ± 7.8	Indoor 23.6 ± 8.8	Male * 27.7 ± 9.6		Tuv 8.6 ± 3.5	Indoor 8.6 ± 1.7	Male 7.9 ± 2.8
			Female 19.4 ± 5.8				Female 9.2 ± 6.0
		Outdoor 26.0 ± 6.7	Male 28.0 ± 6.0			Outdoor 8.6 ± 1.7	Male 8.0 ± 1.3
			Female 24.1 ± 7.1				Female 9.2 ± 2.0
	Sukhbaatar 24.4 ± 8.9	Indoor * 19.6 ± 6.1	Male 21.5 ± 6.5		Sukhbaatar 8.4 ± 2.6	Indoor * 7.5 ± 2.3	Male 7.6 ± 2.8
			Female 17.6 ± 5.4				Female 7.6 ± 2.8
		Outdoor 29.3 ± 8.6	Male 31.0 ± 9.9			Outdoor 9.2 ± 2.7	Male 8.8 ± 2.9
			Female 27.7 ± 7.3				Female 9.7 ± 2.5
	Khovd 17.7 ± 5.1	Indoor * 15.1 ± 4.3	Male 16.2 ± 4.7		Khovd 6.5 ± 2.4	Indoor 6.4 ± 2.1	Male 7.1 ± 2.6
			Female 14.1 ± 3.7				Female 5.8 ± 1.3
		Outdoor 20.3 ± 4.7	Male 21.5 ± 5.9			Outdoor 6.6 ± 2.7	Male 6.7 ± 3.4
			Female 19.1 ± 2.8				Female 6.6 ± 2.0
	Dornod 21.8 ± 7.7	Indoor 19.5 ± 8.9	Male 23.1 ± 10.4		Dornod 6.7 ± 2.8	Indoor 6.1 ± 2.5	Male 7.2 ± 3.5
			Female 16.0 ± 5.5				Female 5.4 ± 1.3
		Outdoor 24.0 ± 5.7	Male 24.9 ± 6.3			Outdoor 7.3 ± 2.9	Male ** 6.0 ± 2.3
			Female 23.1 ± 5.1				Female 8.6 ± 2.9

Table S1.1 (continued)

Values indicate the mean measured 25(OH)D concentration (ng/mL) in each subgroup ± SDs, summer n = 318, winter n = 307. [1] Summer > Winter, $p < 0.05$; [2] p values for regional differences are provided in Table S1.2; [3,*] Within season and region, Indoor < Outdoor, $p < 0.05$; [4,*] Within season, region, and occupation, Male > Female, $p < 0.05$. ** Within season, region, and occupation, Male < Female, $p < 0.05$.

Table S1.2: Statistical significance of regional differences in mean serum 25(OH)D concentration

	Ulaanbaatar	**Omnogobi**	**Bulgan**	**Khuvsgul**	**Tuv**	**Sukhbaatar**	**Khovd**	**Dornod**
Ulaanbaatar		<0.001	0.002	0.07	<0.001	<0.001	1.00	0.13
Omnogobi	<0.001		0.36	0.021	0.65	0.50	<0.001	0.009
Bulgan	<0.001	1.00		0.94	1.00	1.00	0.003	0.86
Khuvsgul	0.044	0.017	0.11		0.75	0.86	0.12	1.00
Tuv	<0.001	0.78	0.99	0.59		1.00	<0.001	0.58
Sukhbaatar	<0.001	0.65	0.96	0.73	1.00		0.001	0.73
Khovd	0.67	<0.001	0.002	0.90	0.042	0.08		0.21
Dornod	0.43	<0.001	0.005	0.98	0.09	0.16	1.00	

Values indicate p values for within-season pairwise comparisons of mean measured 25(OH)D concentration between regions, applying Tukey-Kramer adjustment for multiple comparisons. Upper diagonal: summer; lower diagonal: winter.

II. Projected effectiveness of mandatory industrial fortification of wheat flour, milk, and edible oil with multiple micronutrients among Mongolian adults

Abstract

Background: Industrial fortification of wheat flour is a potentially effective strategy for addressing micronutrient deficiencies in Mongolia, given its ubiquitous consumption and centralized production. However, Mongolia has not mandated fortification of any foods except for salt with iodine.

Methods: We modeled the effectiveness and safety of mandatory industrial fortification of wheat flour alone and in combination with edible oil and milk in reducing the prevalence of multiple micronutrient intake deficiencies among healthy non-pregnant adults in Mongolia. Six days of diet records (3 summer, 3 winter) were collected from 320 urban and rural adults across the country and analyzed for food and nutrient consumption using a purpose-built food composition table, and the Intake Monitoring and Planning Program (IMAPP) was used to project effects of fortification on summer and winter bioavailable micronutrient intake and intake deficiency under different fortification guidelines within population subgroups defined by urban or rural locality and sex.

Results: Flour fortification would be effective in reducing intake deficiencies of thiamin and folate, while marginal benefits of fortification with iron and riboflavin would be smaller given these nutrients' higher baseline consumption, and fortification with zinc, niacin, and vitamin B12 may be unnecessary. Fortification of flour, oil, and milk with vitamins A, D, and E at levels suggested by international guidelines would substantially reduce vitamin A intake deficiency and would increase vitamin D intake considerably, with the greatest benefits elicited by flour fortification and smaller benefits by additionally fortifying oil and milk.

Interpretation: These results support mandatory industrial fortification of wheat flour, edible oil, and milk with iron, thiamin, riboflavin, folate, and vitamins A, D, and E in Mongolia. Considerations will be necessary

to ensure fortification of these nutrients is also effective for children, for whom the potential benefit of zinc, niacin, and vitamin B12 fortification should also be assessed.

Introduction

Mongolians are traditionally a nomadic people who subsisted almost entirely on animal source foods throughout most of their history, owing to Mongolia's poor soil quality and a cold, windy, and dry climate that makes it difficult to grow crops (May 2009). Although wheat flour has become much more important in recent centuries, the modern Mongolian diet still consists largely of dairy products and red meat, and little of fruits, non-tuberous vegetables, legumes, nuts and seeds, and seafood (Komatsu 2006, 2008). Despite steady and impressive progress in curbing wasting, stunting, and low birth weight, a persisting lack of diversity in the Mongolian diet underlies a high prevalence of multiple biochemical micronutrient deficiencies among women and children, including those of iron, vitamin A, and vitamin D (Bromage 2016, PHI 2017). Micronutrient deficiencies in women of reproductive age pose a threat to their health, as well as the health of their offspring during pregnancy and nursing, and may lead to severe and permanent physical and cognitive deficits (Hack 1995, Dewey 2011). Maternal and child supplementation and home-fortification programs have been implemented in Mongolia but have faced challenges achieving desired distribution and compliance, particularly among the more dispersed nomadic herders who still account for approximately one-third of the country's population (Melgarejo 2005, PHI 2017), while efforts to develop and diversify Mongolian agricultural production, the food supply, and the diet have been varyingly hampered by the country's climate, remoteness, and population's historic adherence to a pastoralist food culture (Buell 2006, Baast 2013).

Mongolia is currently at a formative stage in developing its national food fortification policy, with the exception of universal salt iodization which has been an effective measure in reducing the prevalence of biochemical iodine deficiency in the country since its implementation in 1995 (Yamada 1998, Yamada

2002). A program for industrial wheat flour fortification was under development with assistance from the Asian Development Bank (ADB) between 2004 and 2007 but was aborted due to a range of financial, economic, political, procurement-related, and technical concerns among the among the various stakeholders involved (Codling 2015). Nonetheless, wheat flour remains an attractive vehicle for mandatory fortification in Mongolia given its high consumption across all population groups (with 341 grams of wheat and wheat products available per capita per day in the food supply as of 2013 (FAO 2017)), its highly-centralized production system (10 mills process approximately 90% of the country's domestically-produced flour), and the fact that the milling industry gained familiarity and technical experience with industrial fortification as part of the discontinued ADB project (Codling 2015). An intervention study by Tazhibayev and colleagues demonstrated that industrial wheat flour fortification caused statistically significant improvements in plasma folic acid concentrations among Mongolian women of reproductive age (reducing the prevalence of biochemical deficiency by 32%) and non-statistically significant reductions in serum ferritin (Tazhibayev 2008), while studies by our research group have shown fortified milk to be highly effective in raising serum vitamin D concentrations among Mongolian schoolchildren (with locally-fortified milk raising mean serum 25(OH)D by 12 ng/mL more than unfortified milk) (Rich-Edwards 2011). Moreover, a large body of international evidence has demonstrated industrial fortification of staple foods with micronutrients, particularly when mandated by law and appropriately monitored, to be an effective, cost-saving, and safe strategy for improving nutrition in populations (Allen 2004).

In 2017, a bill proposing mandatory fortification of selected foods with multiple micronutrients was introduced to the Mongolian parliament and approved for legislative review in the same year. The purpose of this paper is to broadly inform the regulations falling under the upcoming fortification law with respect to suggested fortification levels for wheat flour and two other potential vehicles (edible oil and milk) by projecting effects that industrial fortification would have on summer and winter bioavailable nutrient intake and prevalence of intake deficiency and over-sufficiency among different Mongolian adult subgroups under multiple fortification guidelines. Projections are based upon baseline data on population food and nutrient consumption collected by our group from 2012-2016 as part of a nationwide nutrition survey.

Methods

Dietary assessment and nutritional analysis of diet

From each of 8 regions of Mongolia (7 national provinces and the municipality of Ulaanbaatar), 10 healthy men and 10 healthy non-pregnant women aged 22-55 years and living in different households were randomly sampled from two geographically-circumscribed areas: the urban area lying within the city limits of a provincial capital and the rural area approximately 1 hour's drive outside one of several smaller district capitals (with the exception of Ulaanbaatar, which was divided into an urban and a peri-urban zone, both of which were considered urban for the purpose of this analysis), providing a sample of 20 urban and 20 rural or peri-urban adults per region (320 participants in total). Participants provided written informed consent prior to enrollment, and ethical approval for the study was obtained from the Mongolian Ministry of Health Ethical Review Board and the Harvard T.H. Chan School of Public Health Institutional Review Board.

From 2012 to 2016, local medical and public health university students were trained to prospectively and unobtrusively collect paired summer and winter 3-day weighed diet records (6 days in total) from each participant, including measured masses of consumed portions, raw ingredients, and cooked dishes. Demographic and lifestyle variables including age, self-reported height and weight, ethnicity, education, supplement use, housing type, and worksite were also assessed by questionnaire. Details of the training and dietary assessment may be found in Bromage 2017a. Collected diet records were translated and entered electronically in Excel by a team of translators, coded by a team of trained analysts according to a uniform protocol and food list, and tabulated to produce total daily consumption of 673 distinct food items on each record day. The content of fortification vehicles (wheat flour, edible oil, and milk) in ingredients, single-ingredient food items, and complex dishes was obtained either by averaging information across collected recipe data or from published equivalency factors (Rosselli 1998, NSO 2015). Total consumption of each nutrient and vehicle by each participant on each day was calculated. See Appendix A for more details on nutritional analysis of diet.

Descriptive statistics

Characteristics of the study population were tabulated for each of four population subgroups (urban male, urban female, rural male, rural female). To help contextualize the sub-national penetration of industrial fortification, the median and associated 1000-sample bootstrap confidence intervals of daily summer and winter consumption of wheat flour, edible oil, and milk in each subgroup were estimated using the R package SPADE (Statistical Program to Assess Dietary Exposure) (Dekkers 2014; see Appendix B for more details on statistical programs), which statistically corrects intake distributions for observed within-person (day-to-day) variation in intake. Medians were estimated using SPADE's 1-part model which assumes dietary components to be consumed in a habitual (daily) rather than an episodic fashion, as verified by inspection of dietary data. To produce more nationally-representative estimates, SPADE models were weighted according to survey weights generated using the 2010 Population and Housing Census of Mongolia as the reference population, incorporating information on age group, sex, urban or rural area, and day of the week (Sonomtseren 2011). Additionally, to describe the sources of wheat flour, edible oil, and milk in the diet, the mean daily fraction of each vehicle's consumption contributed by each of different consumed food groups was calculated for each population subgroup and season and weighted using the survey weights described above.

Outline and assumptions of fortification models

Effects of mandatory industrial food fortification were modeled using the IMAPP software (Intake Monitoring and Planning Program) (WHO 2010; see Appendix B for more details). For each of the 2 seasons (summer and winter) and 4 population subgroups (defined by urban or rural area and sex), models were run to estimate baseline distributions of nutrient intake corrected for within-person-variation, and project the effects of adding iron, zinc, thiamin, riboflavin, niacin, folate, and vitamin B12 to wheat flour, vitamin E to edible oil, and vitamins A and D to wheat flour, edible oil, and milk (in which all combinations of one, two, or three vehicles were individually or simultaneously fortified with vitamins A and D). Milk consumed in rural areas was assumed to be entirely produced at home rather than industrially-processed, as supported by prevailing food consumption patterns in Mongolia (FAO 2007); effects of industrial milk fortification were therefore not modeled for rural areas. See Appendix C for additional assumptions of fortification models.

For each model, IMAPP outputted information on the estimated baseline and projected post-fortification median of daily intake in each subgroup, and the prevalence of nutrient intake deficiency (%<EAR) and over-sufficiency (>%UL) estimated using the EAR cut-point method (IOM 2000). In the case of iron, the cut-point method cannot be accurately applied given iron's logarithmic requirement distribution among pre-menopausal women; IMAPP therefore estimated the post-fortification prevalence of iron intake deficiency using the full-probability approach (IOM 2000). EARs and ULs were drawn from the Harmonized Nutrient Reference Intakes (IOM 2014) and assigned to each participant based on their sex and age in years. In the case of vitamin A, ULs are defined separately for preformed and total vitamin A, the former of which consists of dietary retinol and its ester retinol palmitate (the fortificant modeled in this study); because our dietary data distinguished between intake of retinol and carotenoids, fortification models were able to estimate vitamin A over-sufficiency according to the sum of baseline retinol intake and added retinol palmitate using the retinol-specific UL of 3000 μg/day).

Selection of modeled fortification levels

For each combination of nutrient and vehicle, different fortificant concentrations (informally referred to as "levels") were modeled according to fractions and multiples of, or ranges otherwise suggested by levels found in six national (Mongolian), regional, and international guideline documents (MUST 2009, WHO 2009a, WFP 2011, GSO 2014, FDA 2016, DSM 2017a) (Table 2.1). In the case of iron, World Health Organization (WHO) international flour fortification guidelines suggest fortification levels for high or low flour extraction rates and 5 suitable chemical fortificants; a low extraction rate and iron in the form of ferrous fumarate were selected in accordance with Mongolian national wheat flour fortification guidelines (MUST 2009).

Table 2.1: Fortification levels for wheat flour, edible oil, and milk

Nutrient	Fortificant	Vehicle	Fortification Levels Found in Published National, Regional, and International Reference Guidelines (per 100g of vehicle)		Fortification Levels Modeled in This Study (per 100g of vehicle)				
					Level 0	Level 1	Level 2	Level 3	Level 4
Thiamin	Thiamin mononitrate	Flour	Mongolian National Guideline (MUST 2009):	0.4 mg	0.0 mg	0.2 mg	0.4 mg	0.6 mg	0.8 mg
Riboflavin	Riboflavin	Flour	Mongolian National Guideline (MUST 2009):	0.4 mg	0.0 mg	0.2 mg	0.4 mg	0.6 mg	0.8 mg
Folate	Folic acid	Flour	Low WHO International Guideline (WHO 2009a):	100 µg	0 µg	100 µg	115 µg	130 µg	150 µg
			High WHO International Guideline (WHO 2009a):	130 µg					
			Mongolian National Guideline (MUST 2009):	150 µg					
Vitamin B12	Cyanocobalamin	Flour	Low WHO International Guideline (WHO 2009a):	0.80 µg	0.00 µg	0.80 µg	0.87 µg	0.93 µg	1.00 µg
			High WHO International Guideline (WHO 2009a):	1.00 µg					
Iron	Ferrous fumarate	Flour	Low WHO International Guideline (WHO 2009a):	2.0 mg	0.0 mg	2.0 mg	2.3 mg	2.7 mg	3.0 mg
			High WHO International Guideline (WHO 2009a):	3.0 mg					
			Mongolian National Guideline (MUST 2009):	3.0 mg					
Zinc	Zinc oxide	Flour	Low WHO International Guideline (WHO 2009a):	3.0 mg	0.0 mg	3.0 mg	3.3 mg	3.7 mg	4.0 mg
			High WHO International Guideline (WHO 2009a):	4.0 mg					
Vitamin E	Alpha tocopherol	Oil	Minimum DSM International Guideline (DSM 2017a):	6.5 mg	0.0 mg	6.5 mg	10.7 mg	14.8 mg	19.0 mg
			Maximum DSM International Guideline (DSM 2017a):	19.0 mg					
Niacin	Nicotinamide	Flour	Mongolian National Guideline (MUST 2009):	3.0 mg	0.0 mg	1.5 mg	3.0 mg	4.5 mg	6.0 mg
Vitamin A	Retinol palmitate	Flour	Low WHO International Guideline (WHO 2009a):	100 µg	0 µg	100 µg	117 µg	133 µg	150 µg
			High WHO International Guideline (WHO 2009a):	150 µg					
		Oil	World Food Programme International Guideline (WFP 2011):	900 µg	0 µg	450 µg	900 µg	1350 µg	1800 µg
		Milk	U.S. Food and Drug Administration National Guideline (FDA 2016):	62 µg	0 µg	31 µg	62 µg	93 µg	124 µg
Vitamin D	Cholecalciferol	Flour	GCC Standardization Organization Regional Guideline (GSO 2014):	55 IU	0 IU	28 IU	55 IU	83 IU	110 IU
		Oil	World Food Programme International Guideline (WFP 2011):	300 IU	0 IU	150 IU	300 IU	450 IU	600 IU
		Milk	U.S. Food and Drug Administration National Guideline (FDA 2016):	42 IU	0 IU	21 IU	42 IU	63 IU	84 IU

Low and High WHO International Guidelines are intended to be followed in countries consuming 300+ and 150-300 g/capita/day of wheat flour, respectively. Modeled fortification levels 0-4 are derived as fractions and multiples of, or ranges otherwise suggested by levels found in national, regional, and international reference guidelines. See Methods for modeled bioavailabilities of fortificants. Abbreviations: IU (international unit; 40 IU = 1 μg), GCC (Gulf Cooperation Council), WHO (World Health Organization).

In the case of iron, zinc, vitamin A, folic acid, and vitamin B12, WHO guidelines suggest higher or lower fortification levels depending on whether national wheat flour availability is 150-300 or 300+ g/day, respectively. According to national food balance data, the Mongolian food supply contains 341 g/capita/day of wheat and wheat flour products (FAO 2017). In this study, weighted median summer and winter flour consumption across the four subgroups studied ranged from 189-336 g/day, and in prior analyses (not shown) we obtained nationally-weighted estimates of 207 and 310 g/day from a 2013 dietary assessment and household survey, respectively, collected by the Mongolian University of Science and Technology (MIN 2016), and 277 g/day from analysis of pooled 2012 and 2014 waves of the Mongolian Socio-Economic Survey conducted by the National Statistical Office (NSO 2014). Given the different conclusions that may be drawn depending on the strictness with which one interprets "wheat flour availability", the error associated with national food balance estimates, and the fact that true availability may in fact be close to around 300 g/capita/day, both high and low WHO estimates were considered in addition to Mongolian national guidelines in selecting the ranges of modeled fortification levels for iron, zinc, vitamin A, folic acid, and vitamin B12.

Estimation of fortificant losses and overage factors

Projected effects of each fortification level were modeled three times, first allowing for predicted losses of fortificants during food processing, storage, and cooking, second incorporating overage factors to account for losses during processing and storage, and third (if theoretical cooking losses were non-negligible for the particular nutrient-vehicle combination) incorporating overage for processing, storage, and cooking losses (these three classes of models are indicated as "None" (no overage applied), "PS", and "PSC", respectively, in Supplemental Tables and Figures). For readability, only projections which assume maximum (PSC) overage is included in the main text, while projections under all overage guidelines are given in the Appendix. To help inform a national industrial fortification program in Mongolia, nutrient-specific overage factors (factors by which fortification levels should be multiplied to compensate for food processing, storage, and cooking) were calculated for each food vehicle (Table S2.1). See Appendix D for details on these calculations.

Estimation of optimal fortification levels

In addition to models parameterized according to pre-specified fortification guidelines, an alternate set of models was run for each combination of subgroup, season, and nutrient to estimate subgroup- and season-specific optimal wheat flour fortification levels for adults, which, assuming overage for processing, storage, and cooking, would project a low target prevalence of bioavailable intake deficiency (this analysis excluded vitamin E, flour fortification of which was not considered in this study due to a lack of identified guidelines). The target prevalence was set at 5% for all micronutrients except vitamin D (while 2.5% is the target prevalence used to develop recommended dietary allowances and reference nutrient intakes, a doubly conservative value of 5% was selected under the reasoning that industrial fortification alone is not intended to entirely eliminate micronutrient deficiencies in a population). In the case of vitamin D, a more practical target of 50% was selected given the extremely high baseline prevalence of intake deficiency observed in the study population. For all nutrients except iron, optimal levels were estimated automatically using an iterative process of incremental fortificant addition in IMAPP, termed “closing the gap”; because this process is unable to accommodate iron’s lognormal requirement distribution, optimal levels for iron were instead estimated by manually modeling incremental additions until the target intake deficiency prevalence (5%) was reached based on the full-probability approach. If baseline intake deficiency prevalence of a particular nutrient in a particular subgroup and season was estimated at or below 5%, an optimal level was not estimated but instead simply taken to be 0. Optimal levels were also estimated for edible oil and milk, but were considered too monumental in comparison with published guidelines to be feasible for use in an actual fortification program, and are thus omitted from the results.

Estimated optimal levels were qualitatively compared to published reference guidelines to determine how appropriate the latter would be for application in Mongolia, and the effects of subgroup- and season-specific optimal levels on the prevalence of intake deficiency and over-sufficiency were modeled for both sexes in the same urban or rural area and season. Although optimal levels were derived based on assumptions of maximal overage (for processing, storage, and cooking losses), the effects of these levels were nonetheless modeled under all three overage scenarios considered in analysis of pre-specified fortification guidelines (i.e. no overage, overage for processing and storage losses, and overage for processing, storage, and cooking losses), in order to simulate the effect of considering or neglecting to consider overage in estimating optimal fortification levels (as with projections based on pre-specified fortification levels, only projected effects under maximum overage guidelines are presented in the main text, while effects projected under all overage guidelines are given in the Appendix).

Additional modeled parameters

In addition to the parameters described previously, fortification models also incorporated data on the following:

- Bioavailability of each chemical fortificant stipulated by fortification guideline documents, relative to either the form of the nutrient found in food or to the most bioavailable form, as specified in intake guidelines: ferrous fumarate: 18%; zinc oxide: 50%; retinol palmitate: 90%; folic acid: 166.7%; cyanocobalamin: 200%; cholecalciferol, alpha-tocopherol, thiamin mononitrate, riboflavin, and nicotinamide: 100%. Bioavailabilities were informed by the literature as well as the average meat consumption and phytate:zinc molar ratio observed in the study population (Allen 2004).
- The fraction of milk consumed in urban areas which is industrially produced and thus able to be industrially fortified (20.8%), estimated by dividing the estimated fraction of national milk production currently subject to industrial processing (10.3%) by the fraction of national milk consumption accounted for by urban households (49.3%), assuming no industrially-processed milk is consumed in rural areas (FAO 2007, prior analysis of NSO 2014 (not shown), Munguntuya 2016).

- A moderate prevalence of modern contraceptive use (including oral contraceptives) among women of reproductive age (48.2%) (World Bank 2015), incorporated in modeling the effects of iron fortification.

Results

Population characteristics

Urban participants in this study population were, on average, younger (mean age in urban vs. rural areas: 37.7+9.7 vs. 40.6±9.4 years, respectively), more ethnically homogenous (88% vs. 78% Khalkh Mongolian), more formally educated (14.2±2.8 vs. 10.1±3.7 years), and more likely to consume multivitamins than their rural counterparts (11% vs. 5%), although multivitamin use (expressed as “ever in past 12 months”) was assumed to be uncommon enough in both groups so as not to substantially affect the distribution of baseline nutrient intake (Table 2.2). Mean body mass index of urban and rural participants was 25.9±4.1 and 25.1±3.7 kg/m^3, respectively. Urban participants consisted mostly of office workers (80%) dwelling in a variety of housing types, while rural participants were almost exclusively nomadic herders (99%) living primarily in traditional yurts (94%). The availability of diet records data was 100% in summer and 90 to 94% for rural and urban participants, respectively, in winter. In total, 1,839 person-days of intake data were available for analysis from 320 participants (5.75 days/person).

Table 2.2: Characteristics of study population

Characteristic	**Rural (n=140)**	**Urban (n=180)**
Female sex, n (%)	70 (50)	90 (50)
Age (years), mean (SD)	40.6 (9.4)	37.7 (9.7)
BMI (kg/m^2), mean (SD)	25.1 (3.7)	25.9 (4.1)
Ethnicity, n (%)		
Khalkh	78 (72)	143 (88)
Zakhchin	24 (22)	13 (8)
Other	6 (6)	6 (4)
Education (years), mean (SD)	10.1 (3.7)	14.2 (2.8)
Multivitamin use, n (%) *	7 (5)	19 (11)
Housing, n (%) **		
Yurt	102 (94)	28 (18)
Apartment	1 (1)	42 (26)
House (centrally-heated)	2 (2)	49 (31)
House (no central heating)	3 (3)	41 (26)
Worksite, n (%)		
Outdoor labor	0 (0)	21 (12)
Office	2 (1)	143 (80)
Herder	138 (99)	0 (0)
Factory	0 (0)	6 (3)
Other	0 (0)	9 (5)
Data available for analysis, n (%)		
Summer diet records	140 (100)	180 (100)
Winter diet records	132 (94)	162 (90)

Values represent n (%) or mean (SD). Percentages are calculated after excluding missing values. * Multivitamin use expressed as “Ever during the past twelve months”. ** Housing heating type assessed as an indicator of socioeconomic status. BMI: body mass index.

Consumption and dietary sources of fortification vehicles

Median consumption of wheat flour was highest among rural males in winter (325 g/day), lowest among urban and rural females (range: 183-231), and displayed a seasonal pattern in rural areas such that median winter consumption exceeded summer's by 69 and 46 g/day in males and females, respectively (Figure S2.1). Median consumption of edible oil was lowest among rural females in summer (10.3 g/day), highest among rural males in winter (17.6 g/day), and in urban areas, summer consumption exceeded winter's by 3.4 and 3.8 g/day in males and females, respectively. Median milk consumption was higher in rural areas (range across sexes and seasons: 122-210 g/day) than urban areas (57-69 g/day), and in rural areas displayed a seasonal pattern opposite to that of wheat flour such that median summer consumption exceeded winter's by 42 and 58 g/day in men and women, respectively. Major contributors of dietary wheat flour included steamed, fried, or boiled dumplings (mean percentage of dietary wheat flour across seasons and subgroups: 22.3%); tsuivan, a dish of steamed wheat-flour noodles and stir-fried meat (20.9%); bread and bread with toppings or condiments (20.1%); soups (17.9%); and baked or fried flour products, excluding bread (12.9%); edible oil was consumed primarily from tsuivan (33.4%); boortsog, a deep-fried wheat flour snack similar to a donut (24.6%); huurga, a broad category of meat-based dishes made with various stir-fried and steamed ingredients (20.8%); and dumplings (11.5%) (Figure S2.2). The vast majority of milk was consumed in the form of boiled milk, milk tea, and milk-based soups.

Fortification of wheat flour with thiamin, riboflavin, folic acid, and vitamin B12

A summary of baseline and projected (post-fortification) prevalence of intake deficiency for all 10 nutrients analyzed is given in Table S2.2 and is accompanied by a Policy Brief in Appendix E.

Projected results of wheat flour fortification with four vitamins for which upper limits are not established (thiamin, riboflavin, folate, and vitamin B12) are given in Table 2.3 (under maximum overage guidelines) and Table S2.3 (under all overage guidelines). At baseline, riboflavin intake deficiency is uncommon (range of deficiency prevalence among 8 season-subgroups: 0.6-11.4%) and deficiency of vitamin B12 is almost non-existent. Implementing Level 1 riboflavin fortification, equal to half the level suggested in national wheat flour fortification guidelines published by the Mongolian University of Science and Technology (MUST), would, with maximum overage for processing, storage, and cooking, reduce this range to 0.0-4.6%. By contrast, thiamin and folate intake deficiencies are highly prevalent at baseline (range: 36.2-81.9% and 94.4-100.0%, respectively). Level 2 fortification (equal to the local MUST guideline) with maximum overage would reduce the range of thiamin and folate deficiency prevalence to 0.1-14.7% and 0.1-22.1%, respectively, leaving urban females with the only projected deficiency prevalence of thiamin above 4.4% and folate above 7.4% in either season.

Table 2.3: Prevalence of thiamin, riboflavin, folate, and vitamin B12 intake deficiency (%<EAR) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour fortification guidelines

	Subgroup:	**Rural Females**		**Rural Males**		**Urban Females**		**Urban Males**	
Nutrient	**Fortification Level**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Thiamin	0	65.0	81.9	36.2	53.4	58.4	73.5	53.3	62.5
	1	14.3	23.2	9.2	2.4	19.0	34.1	9.5	15.0
	2	1.2	4.4	2.6	0.1	5.8	14.7	1.0	2.1
	3	0.0	1.0	1.0	0.0	2.0	6.9	0.1	0.3
	4	0.0	0.3	0.4	0.0	0.8	3.5	0.0	0.0
Riboflavin	0	3.4	10.9	5.3	0.6	8.0	11.4	11.2	4.8
	1	0.3	1.3	1.2	0.0	2.3	4.6	2.1	0.6
	2	0.0	0.2	0.5	0.0	0.8	1.8	0.5	0.0
	3	0.0	0.0	0.2	0.0	0.3	0.9	0.1	0.0
	4	0.0	0.0	0.2	0.0	0.1	0.5	0.0	0.0
Folate	0	100.0	99.3	97.1	97.1	99.7	99.0	98.0	94.4
	1	12.3	12.4	6.3	0.3	18.7	29.4	1.0	1.4
	2	3.9	7.4	4.3	0.1	13.1	22.1	0.3	0.6
	3	1.2	4.4	2.8	0.0	9.3	16.8	0.1	0.3
	4	0.2	2.4	1.5	0.0	5.8	11.6	0.0	0.1
Vitamin B12	0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Values represent the percentage of each subgroup's nutrient intake lying below the subgroup-specific estimated average requirement (EAR) at baseline (Level 0) and projected under different fortification levels and maximum overage guidelines for processing, storage, and cooking. Shading indicates the extent of projected intake deficiency (0%: green; 50%: yellow; 100%: red). See Methods and Table 2.1 for description of levels and references.

Fortification of wheat flour and edible oil with iron, zinc, vitamin E, and niacin

Projected results of wheat flour and oil fortification with four micronutrients for which upper limits are established (iron, zinc, vitamin E, and niacin) are given in Table 2.4 (under maximum overage guidelines) and Table S2.4 (under all overage guidelines). The baseline prevalence of iron intake deficiency is moderate among urban and rural females (range of deficiency prevalence among 4 season-subgroups: 10.6-22.2%; over-sufficiency prevalence: 0.0%) but not males (range of deficiency: 0.0-0.5%; over-sufficiency: 0.0-0.3%). Iron fortification of flour at Level 1 (the lower level suggested by the WHO guideline for Mongolia), ensuring maximum overage, would eliminate deficiency and project a modest increase in the prevalence of over-sufficiency among males (range: 0.0-1.3%), and would project a significant reduction in deficiency among females (range: 3.5-11.1%; over-sufficiency: 0.0-0.1%). The baseline prevalence of zinc intake deficiency and over-sufficiency are low (range of deficiency across 8 season-subgroups: 0.3-2.1%; over-sufficiency: 0.0-3.7%). Flour fortification at Level 1 (the lower WHO guideline for Mongolia), with maximum overage, would all but eliminate deficiency (range: 0.0-0.2%) while projecting a considerable increase in the prevalence of over-sufficiency among urban and rural males (range across 4 season-subgroups: 9.0-25.4%) and less so among females (range: 0.0-3.8%).

Table 2.4: Prevalence of iron, zinc, vitamin E, and niacin intake deficiency (%<EAR) and over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour or oil fortification guidelines

	Subgroup:	**Rural Females**				**Rural Males**				**Urban Females**				**Urban Males**			
	Season:	**Summer**		**Winter**		**Summer**		**Winter**		**Summer**		**Winter**		**Summer**		**Winter**	
Nutrient (Vehicle)	**Fortification Level**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**	%< **EAR**	%> **UL**
Iron (Flour)	0	18.7	0.0	10.6	0.0	0.5	0.0	0.0	0.0	16.8	0.0	22.2	0.0	0.2	0.0	0.0	0.3
	1	7.3	0.0	3.5	0.0	0.0	1.3	0.0	0.3	7.5	0.1	11.1	0.0	0.0	0.0	0.0	1.2
	2	5.7	0.0	2.9	0.0	0.0	1.8	0.0	0.5	6.8	0.2	9.8	0.1	0.0	0.1	0.0	1.5
	3	4.7	0.0	2.1	0.0	0.0	2.5	0.0	0.8	6.0	0.2	8.5	0.2	0.0	0.2	0.0	1.9
	4	3.9	0.0	1.9	0.0	0.0	3.2	0.0	1.2	5.1	0.3	8.0	0.2	0.0	0.3	0.0	2.7
Zinc (Flour)	0	1.4	0.0	1.9	0.0	0.8	3.7	0.5	1.6	2.1	0.4	0.3	0.3	0.5	0.4	0.8	2.9
	1	0.0	0.0	0.1	1.3	0.0	15.6	0.0	25.4	0.2	3.8	0.0	0.5	0.0	9.0	0.0	15.5
	2	0.0	0.0	0.0	2.0	0.0	18.8	0.0	30.6	0.1	4.9	0.0	0.8	0.0	11.9	0.0	18.4
	3	0.0	0.0	0.0	2.9	0.0	22.4	0.0	36.2	0.1	6.3	0.0	1.3	0.0	15.3	0.0	21.9
	4	0.0	0.0	0.0	3.9	0.0	26.4	0.0	42.0	0.1	7.8	0.0	1.8	0.0	19.1	0.0	25.4
Vitamin E (Oil)	0	100.0	0.0	99.7	0.0	98.8	0.0	99.8	0.0	98.8	0.0	99.0	0.0	100.0	0.0	99.5	0.0
	1	100.0	0.0	99.0	0.0	95.2	0.0	97.8	0.0	97.2	0.0	97.6	0.0	98.0	0.0	97.4	0.0
	2	100.0	0.0	98.1	0.0	91.8	0.0	93.6	0.0	95.0	0.0	96.1	0.0	93.8	0.0	94.7	0.0
	3	99.8	0.0	96.9	0.0	87.1	0.0	86.8	0.0	91.5	0.0	94.2	0.0	85.4	0.0	90.0	0.0
	4	99.4	0.0	95.1	0.0	81.4	0.0	77.9	0.0	86.7	0.0	92.0	0.0	72.5	0.0	84.8	0.0
Niacin (Flour)	0	11.6	0.0	13.0	0.1	3.4	6.1	0.5	15.4	10.9	1.2	13.4	0.2	2.2	6.8	2.0	12.7
	1	2.8	0.0	3.5	0.6	1.3	18.4	0.0	33.2	4.5	4.0	6.4	0.9	0.5	16.3	0.5	22.8
	2	0.5	0.2	0.8	2.8	0.6	34.4	0.0	57.2	2.0	9.9	3.2	3.8	0.1	31.9	0.1	36.2
	3	0.0	0.9	0.5	10.7	0.3	49.7	0.0	78.7	1.0	19.1	1.8	9.6	0.0	50.2	0.0	51.2
	4	0.0	3.8	0.2	22.9	0.2	63.7	0.0	90.9	0.5	30.1	1.1	18.2	0.0	67.0	0.0	65.4

Values represent the percentage of each subgroup's nutrient intake lying below the subgroup-specific estimated average requirement (EAR) or above its upper limit (UL), respectively, at baseline (Level 0) and projected under different fortification levels and maximum overage guidelines for processing, storage, and cooking. Shading indicates the extent of projected intake deficiency or over-sufficiency (0%: green; 50%: yellow; 100%: red). See Methods and Table 2.1 for description of levels and references.

By contrast, baseline vitamin E intake deficiency prevalence is extremely high (range across 8 season-subgroups: 98.8-100%) with no prevalence of over-sufficiency. Oil fortification at Level 2 (the DSM international guideline), with overage for processing, cooking, and storage, would have a relatively small effect on deficiency prevalence (range across 8 subgroups and seasons: 91.8-100%) without affecting that of over-sufficiency. In the case of niacin, the baseline prevalence of intake deficiency and over-sufficiency are qualitatively opposite between males (range of deficiency prevalence across 4 seasons-subgroups: 0.5-3.4%; over-sufficiency: 6.1-15.4%) and females (deficiency: 10.9-13.4%; over-sufficiency: 0.0-1.2%). Flour fortification at Level 1 (half the local guideline), with maximum overage, would reduce the range of intake deficiency prevalence among males (0.0-1.3%) and females (2.8-6.4%) while considerably increasing that of over-sufficiency in males (16.3-33.2%) but not females (0.0-4.0%).

Fortification of wheat flour, edible oil, and milk with vitamin A

Flour and oil fortification, simultaneously or on their own, would substantially reduce the prevalence of vitamin A intake deficiency. Baseline vitamin A deficiency is common in urban areas (range across 4 season-subgroups: 46.4-73.4%; Figure S2.3) and rural areas (40.0-71.3%; Tables 2.5 and S2.5), while over-sufficiency is less common (urban: 0.0-14.3%; rural: 0.4-5.2%; Figure S2.4, Tables 2.5 and S2.5) (see note in next paragraph regarding over-sufficiency estimates for vitamin A). Flour fortification at Level 2 (116.7 µg retinol palmitate/100g flour), with maximum overage, would reduce these deficiency ranges to 14.3-41.8% and 5.2-40.8% in urban and rural areas, respectively (over-sufficiency: 0.2-10.0% and 0.6-4.6%, respectively), while Level 2 oil fortification (the level suggested in World Food Programme (WFP) international guidelines) would reduce deficiency to 26.9-56.4% and 26.9-61.2% (over-sufficiency: 0.1-8.3% and 0.0-5.1%). Together, flour and oil fortification at these guidelines would reduce the ranges of urban and rural deficiency prevalence to 8.3-30.0% and 0.6-24.9%, respectively (over-sufficiency: 1.2-9.7% and 0.1-5.3%). Fortification of milk alone would have a small effect on deficiency prevalence in urban areas: 45.1-71.8% (over-sufficiency: 0.0-13.8%); with oil: 26.5-55.2% (over-sufficiency: 0.1-7.3%);

with flour: 13.1-40.6% (over-sufficiency: 0.2-9.7%); with flour and oil: 7.6-29.1% (over-sufficiency: 0.2-9.7%).

Table 2.5: Prevalence of vitamins A and D intake deficiency (%<EAR) and over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour and oil fortification guidelines (rural areas)

	Nutrient:	Vitamin A								Vitamin D							
	Sex:	Females				Males				Females				Males			
	Season:	Summer		Winter		Summer		Winter		Summer		Winter		Summer		Winter	
Flour Fortification Level	Oil Fortification Level	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL
0	0	40.0	0.6	71.3	0.4	49.1	2.8	41.5	5.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	1	35.8	2.1	67.3	0.0	43.5	5.3	32.7	6.3	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	2	30.5	1.3	61.2	0.0	35.6	5.1	26.9	2.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	3	23.9	0.8	54.5	0.0	27.9	5.0	20.5	1.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	4	18.2	0.6	44.7	0.0	21.1	5.1	15.0	0.7	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
1	0	17.0	1.6	45.5	1.4	26.4	4.5	9.1	0.9	100.0	0.0	100.0	0.0	99.8	0.0	100.0	0.0
	1	13.1	1.1	37.4	1.0	19.6	5.0	3.9	0.5	100.0	0.0	100.0	0.0	99.5	0.0	100.0	0.0
	2	9.5	0.8	29.9	0.7	14.0	5.2	1.5	0.2	100.0	0.0	100.0	0.0	98.9	0.0	100.0	0.0
	3	6.5	0.7	22.8	0.6	9.5	5.3	0.4	0.2	100.0	0.0	100.0	0.0	97.5	0.0	100.0	0.0
	4	4.3	0.4	15.8	0.5	6.5	5.5	0.1	0.0	100.0	0.0	99.9	0.0	95.1	0.0	99.5	0.0
2	0	13.3	1.5	40.8	1.4	22.5	4.6	5.2	0.6	100.0	0.0	100.0	0.0	96.5	0.0	100.0	0.0
	1	10.1	0.9	32.6	1.2	16.4	5.2	1.9	0.3	100.0	0.0	100.0	0.0	93.8	0.0	100.0	0.0
	2	7.0	0.8	24.9	0.8	11.2	5.3	0.6	0.1	100.0	0.0	99.9	0.0	89.7	0.0	99.1	0.0
	3	4.9	0.6	19.1	0.7	7.6	5.6	0.1	0.0	100.0	0.0	99.6	0.0	84.6	0.0	95.6	0.0
	4	3.2	0.3	13.6	0.6	5.1	5.8	0.0	0.0	100.0	0.0	98.5	0.0	78.5	0.0	88.8	0.0
3	0	10.2	1.3	35.6	1.5	19.0	4.8	2.5	0.3	100.0	0.0	99.6	0.0	83.1	0.0	96.5	0.0
	1	7.4	0.9	27.9	1.2	13.7	5.4	0.8	0.2	100.0	0.0	98.7	0.0	77.1	0.0	89.8	0.0
	2	4.7	0.7	21.1	0.9	9.2	5.5	0.2	0.0	100.0	0.0	97.0	0.0	70.3	0.0	79.1	0.0
	3	3.3	0.6	15.6	0.8	6.2	6.0	0.0	0.0	100.0	0.0	94.5	0.0	63.1	0.0	67.5	0.0
	4	2.0	0.3	10.7	0.6	4.3	6.2	0.0	0.0	99.8	0.0	90.8	0.0	55.2	0.0	55.9	0.0
4	0	7.6	0.3	31.1	1.5	15.9	5.0	1.0	0.2	100.0	0.0	93.3	0.0	61.0	0.0	63.2	0.0
	1	5.1	0.7	23.3	1.2	11.3	5.5	0.2	0.0	100.0	0.0	89.2	0.0	54.6	0.0	51.0	0.0
	2	3.4	0.6	17.8	1.0	7.5	5.9	0.0	0.0	99.8	0.0	84.8	0.0	47.9	0.0	40.3	0.0
	3	2.2	0.5	12.4	0.9	5.0	6.2	0.0	0.0	99.1	0.0	79.0	0.0	41.3	0.0	31.1	0.0
	4	1.3	0.3	8.4	0.8	3.4	6.6	0.0	0.0	97.7	0.0	73.6	0.0	35.1	0.0	24.0	0.0

Values represent the percentage of each rural subgroup's nutrient intake lying below the subgroup-specific estimated average requirement (EAR) or above its upper limit (UL), respectively, at baseline (Level 0) and projected under different fortification levels and maximum overage guidelines for processing, storage, and cooking. Shading indicates the extent of projected intake deficiency or over-sufficiency (0%: green; 50%: yellow; 100%: red). See Methods and Table 2.1 for description of levels and references.

Table 2.6: Median intake of D (IU/day) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour and oil fortification guidelines (rural areas)

	Sex:	Females		Males	
	Season:	Summer	Winter	Summer	Winter
Flour Fortification Level	Oil Fortification Level	IU/day	IU/day	IU/day	IU/day
0	0	29.1	18.2	41.1	31.3
	1	40.8	36.8	70.0	58.1
	2	52.1	53.2	97.2	82.8
	3	63.0	69.5	122.9	107.1
	4	73.8	85.3	148.7	131.6
1	0	78.5	82.0	123.4	119.5
	1	89.8	98.2	148.7	143.9
	2	100.8	114.4	174.7	167.7
	3	111.8	130.3	200.1	191.9
	4	122.6	146.3	225.7	215.8
2	0	127.3	144.0	202.2	204.6
	1	138.2	160.3	228.0	228.8
	2	149.3	176.2	253.4	252.7
	3	160.0	192.0	278.2	276.5
	4	171.2	207.8	303.8	300.3
3	0	175.9	206.1	281.8	289.5
	1	186.8	222.1	305.8	313.5
	2	197.8	238.1	330.3	337.2
	3	208.7	253.8	355.1	362.9
	4	219.7	269.0	381.7	386.7
4	0	224.3	268.0	360.2	374.2
	1	235.4	284.0	383.1	398.0
	2	246.3	300.3	407.7	421.9
	3	257.3	300.3	433.4	447.7
	4	268.2	300.3	459.9	472.1
Female Optimum	0	400.0	400.0	635.0	557.9
Male Optimum	0	252.1	285.5	400.0	400.0

Values represent the median intake of vitamin D (IU/day) in each rural subgroup at baseline (Level 0) and projected under different fortification levels and maximum overage guidelines for processing, storage, and cooking. Shading indicates the magnitude of projected median intake (minimum (18.2 IU/day): red; median (208.3 IU/day): yellow; estimated average requirement (400.0 IU/day): green). See Methods and Table 2.1 for description of Levels 0-4 and references, and methods and Table 2.9 for description and specifications of male and female optimal levels. IU: international unit (40 IU = 1 µg).

The results of most vitamin A fortification models project a paradoxical decrease in the prevalence of over-sufficiency as fortification levels increase. The summer and winter distributions of vitamin A intake within each of the 4 subgroups, particularly vitamin A from retinol, appeared significantly more right-skewed than those of any of the other 9 nutrients analyzed in this study. Extreme right-skew in vitamin A measurements is often attributed to vitamin A's high intra-person variation, which generally requires many more days of dietary data to be collected than other vitamins or minerals to allow a precise estimate of long-term intake (Willett 2013); in light of this population's relatively monotonous diet, particularly in rural areas, skew is more attributable to high (but not highly variable within persons) consumption of organ meats and dairy products among certain consumers. It is therefore likely that while IMAPP was capable of accurately drawing the left tail of baseline and projected vitamin A intake distributions in this study, it usually lacked sufficient statistical information to accurately draw the right tail. As a result, while estimates of vitamin A intake deficiency prevalence and median intake are estimated accurately, estimates of over-sufficiency prevalence are estimated poorly and should not serve as a basis for inference about the larger Mongolian adult population.

Fortification of wheat flour, edible oil, and milk with vitamin D

At baseline, the population is wholly (100%) intake deficient in vitamin D (Figure S2.5, Table 2.5 and S2.5). Simultaneous Level 2 fortification of wheat flour, edible oil, and (in urban areas) milk (the level suggested by Gulf Cooperation Council Standardization Organization (GSO) regional, WFP international, and FDA (Food and Drug Administration) national guidelines, respectively), would have a fairly modest effect on the range of deficiency prevalence in urban areas (range across 4 season-subgroups: 97.4-99.0%) and rural areas (89.7-100%). However, these measures would increase median intake dramatically. At baseline, median intake across 4 season-subgroups ranges from 32-52 IU/day in urban areas and 18-41 IU/day in rural areas (Figure S2.6, Tables 2.6 and S2.6). Upon fortification of flour at Level 2 (the GSO regional guideline), these urban and rural ranges increase to 147-201 and 127-204 IU/day, respectively. Oil fortification at Level 2 (the DSM international guideline) would also be effective, increasing the ranges of urban and rural median intake to 79-116 and 52-97 IU/day, respectively, while the combination of Level 2 flour and oil fortification would result in urban and rural ranges of 154-263 and 149-253 IU/day, respectively. Level 2 milk fortification (the FDA national guideline) would be relatively ineffective in increasing median intake in urban areas: 31-58 IU/day; with flour: 133-208 IU/day; with oil: 62-122 IU/day; with both flour and oil: 161-269 IU/day. Neither at baseline nor after modeling Level 4 fortification of all three vehicles simultaneously (twice the levels suggested in the GSO, WFP, and FDA guidelines) is the prevalence of vitamin D over-sufficiency projected to exceed 0% in any of the 8 season-subgroups considered.

Optimal fortification levels for wheat flour

Tables 2.7 and 2.8 compare the range of published national, regional, and international wheat flour fortification levels (reproduced from Table 2.1) to the optimal fortification levels estimated for Mongolian adults in this study, for each nutrient, population subgroup, and season, and show how implementing these optimal levels would affect season-specific prevalence of intake deficiency and over-sufficiency among males and females in the same urban or rural areas under maximum overage guidelines (see Tables S2.7 and S2.8 for projected effects under all overage guidelines). Results of this analysis suggest that of all the nutrients considered in this study, the published national guideline for thiamin alone may be close to optimal for adults in Mongolia (assuming appropriate overage is applied). National guidelines for riboflavin and niacin, international guidelines for zinc and vitamin B12, and both national and international guidelines for iron may be too high (suggesting that fractions of published guidelines may be optimal for adults), while national and international guidelines for folate and vitamin A may be too low (suggesting that multiples may be optimal). Tables 2.8 and S2.8 also indicate that, although not intended for use in Mongolia, the fortification level suggested by the regional GSO guideline for vitamin D is also below the optimum for Mongolian adults. For certain nutrients there is a wide range in estimated optimal fortification levels across seasons and subgroups, including folate (range: 104-337 µg/100 g), vitamin A (106-267 µg/100 g), and vitamin D (118-209 IU/100 g).

Table 2.7: Estimated optimal flour fortification levels for thiamin, riboflavin, and folate, and their projected effects on the prevalence of intake deficiency (%<EAR) among different subgroups of Mongolian adults in summer and winter

Area and Season:			**Rural Summer**			**Rural Winter**		
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Optimum**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%<EAR, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%<EAR, Males**
Thiamine	0.4 mg	Female Optimum	0.3 mg	4.8	5.2	0.4 mg	4.8	0.1
		Male Optimum	0.3 mg	4.3	4.9	0.2 mg	31.8	4.4
Riboflavin	0.4 mg	Female Optimum	0.0 mg	3.4	5.3	0.1 mg	4.7	0.0
		Male Optimum	0.0 mg	3.1	4.9	0.0 mg	10.9	0.6
Folate	100 µg, 130 µg, 150 µg	Female Optimum	187.0 µg	4.9	4.7	210.7 µg	5.0	0.0
		Male Optimum	183.2 µg	6.1	5.0	104.1 µg	42.1	5.0
Vitamin B12	0.80 µg, 1.00 µg	Female Optimum	0.0 µg	0.0	0.0	0.0 µg	0.0	0.0
		Male Optimum	0.0 µg	0.0	0.0	0.0 µg	0.0	0.0
Area and Season:			**Urban Summer**			**Urban Winter**		
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Optimum**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%<EAR, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%<EAR, Males**
Thiamine	0.4 mg	Female Optimum	0.4 mg	5.0	0.7	0.7 mg	4.9	0.1
		Male Optimum	0.3 mg	13.3	4.9	0.3 mg	20.4	4.7
Riboflavin	0.4 mg	Female Optimum	0.1 mg	4.8	5.6	0.2 mg	4.8	0.7
		Male Optimum	0.1 mg	4.2	4.7	0.0 mg	11.4	4.8
Folate	100 µg, 130 µg, 150 µg	Female Optimum	260.7 µg	5.0	0.0	336.7 µg	5.0	0.0
		Male Optimum	129.2 µg	31.7	5.0	133.6 µg	42.9	5.0
Vitamin B12	0.80 µg, 1.00 µg	Female Optimum	0.0 µg	0.5	0.0	0.0 µg	0.0	0.0
		Male Optimum	0.0 µg	0.5	0.0	0.0 µg	0.0	0.0

"Optimal Level" represents the estimated concentration of nutrient needed to achieve a post-fortification intake deficiency prevalence of 5% in a specific urban or rural area, season, and sex under maximum overage guidelines for processing, storage, and cooking (if the baseline prevalence is equal to or less than 5%, the optimal level is set to 0). For comparison, published levels are reproduced from Table 2.1. The projected effect of each area-, season-, and sex-specific optimal level on the prevalence of deficiency (%<EAR) is modeled for both sexes in the same area and season under maximum overage guidelines for processing, storage, and cooking. Shading indicates the extent of projected deficiency (0%: green; 50%: yellow; 100%: red).

Table 2.8: Estimated optimal flour fortification levels for zinc, vitamin A, vitamin D, and niacin, and their projected effects on the prevalence of intake deficiency (%<EAR) and over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter

		Area and Season:	**Rural Summer**					**Rural Winter**				
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Guideline**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**
Iron	2.0 mg, 3.0 mg	Female Optimum	2.6 mg	5.1	0.0	0.0	2.4	1.3 mg	5.0	0.0	0.0	0.0
		Male Optimum	0.0 mg	18.7	0.0	0.5	0.0	0.0 mg	10.6	0.0	0.0	0.0
Zinc	3.0 mg, 4.0 mg	Female Optimum	0.0 mg	1.4	0.0	0.8	0.2	0.0 mg	1.9	0.0	0.5	2.5
		Male Optimum	0.0 mg	1.4	0.0	0.8	0.2	0.0 mg	1.9	0.0	0.5	2.5
Vitamin A	100 µg, 150 µg	Female Optimum	151.8 µg	5.0	0.3	12.7	5.2	267.0 µg	5.0	2.1	0.0	0.0
		Male Optimum	210.5 µg	1.0	0.3	5.0	6.0	105.5 µg	40.6	1.4	5.0	0.6
Vitamin D	55 IU	Female Optimum	209.4 IU	50.0	0.0	11.6	0.0	168.7 IU	50.0	0.0	7.6	0.0
		Male Optimum	125.7 IU	100.0	0.0	50.0	0.0	117.8 IU	89.1	0.0	50.0	0.0
Niacin	3.0 mg	Female Optimum	0.9 mg	5.0	0.0	1.8	12.9	1.1 mg	5.0	0.5	0.0	28.0
		Male Optimum	0.0 mg	11.6	0.0	3.4	6.1	0.0 mg	13.0	0.1	0.5	15.4

		Area and Season:	**Urban Summer**					**Urban Winter**				
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Guideline**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**
Iron	2.0 mg, 3.0 mg	Female Optimum	3.1 mg	5.0	0.4	0.0	0.4	4.6 mg	5.0	1.2	0.0	7.8
		Male Optimum	0.0 mg	16.8	0.0	0.2	0.0	0.0 mg	22.2	0.0	0.0	0.3
Zinc	3.0 mg, 4.0 mg	Female Optimum	0.0 mg	2.1	0.1	0.5	0.2	0.0 mg	0.3	0.0	0.8	1.0
		Male Optimum	0.0 mg	2.1	0.1	0.5	0.2	0.0 mg	0.3	0.0	0.8	1.0
Vitamin A	100 µg, 150 µg	Female Optimum	220.6 µg	5.0	1.2	6.8	5.3	395.3 µg	5.0	1.1	0.0	10.5
		Male Optimum	240.5 µg	3.8	1.3	5.0	5.7	176.0 µg	24.6	0.3	5.0	9.1
Vitamin D	55 IU	Female Optimum	178.8 IU	50.0	0.0	9.7	0.0	207.1 IU	50.0	0.0	8.0	0.0
		Male Optimum	129.4 IU	78.6	0.0	50.0	0.0	135.0 IU	85.6	0.0	50.0	0.0
Niacin	3.0 mg	Female Optimum	1.3 mg	5.0	3.4	0.5	14.6	2.0 mg	5.0	1.6	0.3	26.9
		Male Optimum	0.0 mg	10.9	1.2	2.2	6.8	0.0 mg	13.4	0.2	2.0	12.7

"Optimal Level" represents the estimated concentration of nutrient needed to achieve a post-fortification intake deficiency prevalence of 5% (50% in the case of vitamin D) in a specific urban or rural area, season, and sex under maximum overage guidelines for processing, storage, and cooking (if the baseline prevalence is equal to or less than this percentage, the optimal level is set to 0). For comparison, published are reproduced from Table 2.1. The projected effect of each area-, season-, and sex-specific optimal level on the prevalence of deficiency (%<EAR) and over-sufficiency (%>UL) is modeled for both sexes in the same area and season under maximum overage guidelines for processing, storage, and cooking. Shading indicates the extent of projected deficiency or over-sufficiency (0%: green; 50%: yellow; 100%: red). IU: international unit (40 IU = 1 µg).

Discussion

This study provides seminal evidence for the expected effectiveness of mandatory industrial fortification of wheat flour, edible oil, and milk with multiple micronutrients in the Mongolian adult population. At baseline, intake deficiencies of thiamin, folate, and vitamins A, D, and E are particularly severe, with women bearing somewhat greater burdens of thiamin, vitamin A, and iron deficiency. Among different urban/rural- and sex-subgroups of the population in both summer and winter, we project that fortification of wheat flour with thiamin, folic acid, vitamin A, and vitamin D would be highly effective in reducing the prevalence of bioavailable intake deficiency of all four vitamins except vitamin D, intake of which would still increase substantially. The benefit of additionally fortifying oil with vitamins A, D, and E would be smaller but would still elicit significant increases in intake, while in the case of milk, fortification is projected to be relatively ineffective due in part to the fact that that a large fraction of milk consumed in urban areas is not currently subject to industrial processing and is thus not able to be fortified. Milk fortification is still advised, however, given that this fraction is expected to shrink as Mongolia becomes increasingly commercially industrialized. Because baseline consumption of iron and riboflavin in proportion to intake requirements is relatively high in this population, lower levels of flour fortification would be appropriate and sufficient to address intake deficiency of these micronutrients. This analysis alone does not support fortification of flour with zinc and niacin (projected risks of over-sufficiency outweigh reductions in deficiency), and vitamin B12 (baseline deficiency prevalence is minimal); however, fortification with these nutrients should not be discounted without considering potential benefits that may be incurred in subpopulations other than healthy men and women. In most cases, accounting for overage to compensate for losses in processing and storage, in addition to cooking losses, has a significant effect on the projected effectiveness of fortification.

Comment on specific micronutrients

The present study demonstrated bioavailable folate intake deficiency to be extremely widespread in most of the adult population, and that fortification of wheat flour with folic acid would dramatically reduce deficiency prevalence. Prior research by Tazhibayev and colleagues demonstrated that biochemical folate deficiency could be effectively addressed in Mongolia through wheat flour fortification (Tazhibayev 2008). Folic acid fortification of wheat flour is also supported by a large body of international evidence as to its effectiveness in preventing neural tube defects (Allen 2004); incidentally, national statistics on these and other congenital abnormalities show a remarkably low prevalence compared to that which would be expected for Mongolia, but this is likely due to profound underestimation given inadequate enumeration of data sources and exclusion of stillbirths and terminations (Berry 2010, FFI 2017, Goodman 2017). Intake deficiencies of two other B vitamins frequently added to wheat flour, thiamin and riboflavin, were found to be common in the case of thiamin (particularly among women) and relatively uncommon for riboflavin. As in most countries, information on the extent or severity of biochemical deficiency of these vitamins is unavailable for Mongolia, but it is likely that subclinical deficiency is a significant public health problem in this and other developing regions, and that their addition to wheat flour would be a prudent measure (Allen 2004).

Prior research by our group and others has demonstrated extremely low levels of consumption and biochemical status of vitamin D among Mongolians of different ages across the country, a high prevalence of rickets nationwide, and that vitamin D fortification of milk consumed by school children was effective in ameliorating biochemical vitamin D deficiency (Rich-Edwards 2011, Bromage 2016, PHI 2017). We have also observed beneficial effects of vitamin D supplementation on child growth and risk of respiratory infections and atopic dermatitis in Mongolia (Ganmaa 2012, 2017; Camargo 2012, 2014). Fortification models project that the range of median intake among Mongolian adults aged 22-55 after fortification of wheat flour, edible oil, and milk at levels suggested by regional and international guidelines (154.4-269.0 IU/day) exceeds median intake from food among adults aged 19-50 in the United States (144-192 IU/day), a country where most milk is fortified with vitamin D and rickets is rare despite a 94% prevalence of intake deficiency (DGAC 2015) (while widespread subclincial deficiency may persist at these intake levels, these levels are far above those associated with rickets and osteomalacia, which describe extreme clinical deficiency). Thus, while fortification levels modeled in the current study would not substantially reduce the prevalence of intake deficiency (defined according to a relatively conservative guideline of 400 IU/day), a potentially dramatic marginal benefit to health of increasing vitamin D intake in Mongolia may be expected given the extremely low intake at baseline (Pettifor 2004).

Intake deficiencies of two other fat-soluble vitamins, A and E, were also found to be common in the current study and would respond well to fortification. While biochemical vitamin E status of the Mongolian population is unknown, ten percent of children aged 6 to 59 months in Mongolia are vitamin A deficient (RBP <0.7μmol/l) (PHI 2017). Furthermore, the extent of intake deficiency observed in the current study suggests that subclinical biochemical deficiency among adults may be common, which may have particular implications during pregnancy and lactation (WHO 2009b). Subclinical vitamin E deficiency, while less well-characterized in terms of its consequences, may have important implications for chronic disease risk later in life (Eitenmiller 2004).

An important finding of this study is the high observed baseline bioavailable intake of niacin, vitamin B12, iron, and zinc in the study population, and the correspondingly lower baseline prevalence of intake deficiency and lower marginal effectiveness of flour fortification in curbing intake deficiency of these nutrients. To the authors' knowledge, with the exception of this study, recent data on population niacin, vitamin B12, or zinc consumption or biochemical status are unavailable for Mongolian adults, while a moderate prevalence of biochemical iron deficiency has been observed in women but not men (PHI 2017). National data on the prevalence of genetic iron disorders are unavailable for Mongolia. It is plausible that biochemical iron deficiency among healthy adults is at least mitigated by Mongolians' generally high consumption of meat and organs, which are excellent sources of the more bioavailable heme form of iron and which have been implicated in high concentrations of iron found in Mongolians' hair (Komatsu 2011). In fact, among 175 national food supplies, that of Mongolia was estimated to contain the fifth highest fraction of calories per capita originating from meat (18.1%) in 2013 (FAO 2017), and almost all participants surveyed in this study consumed at least some meat or meat-containing product on every day of study.

Comment on overage factors and optimal levels

This analysis also indicates the potentially severe extent to which estimated optimal levels may fail to address micronutrient intake deficiency in Mongolia if such levels are developed without appropriate application of overage factors. Model results for folate and vitamin D provide salient examples of this. Folate in flour products suffers formidable losses in processing and storage (between 10 to 60%; DSM 2017b) and in baking, steaming, boiling, frying, or reheating flour or flour products (5-50% may be destroyed; Bognár 2002, NDL 2007). For this reason, the estimated optimal folic acid fortification level for rural females in summer of 187 μg folate/100 g wheat flour would only yield a target intake deficiency prevalence of 5% if overage is appropriately applied; if not, a projected 73.2% of this subgroup would remain deficient in summer. On the other hand, only 15-35% of vitamin D is lost in processing and storage of flour and flour products, and the vitamin is quite stable in this medium during cooking. However, given how right-skewed the distribution of vitamin D intake is in this population, even a relatively small difference in fortification levels (such as that incurred by ensuring appropriate overage) may significantly affect the projected intake deficiency prevalence. Returning to the example of rural females in summer, if overage is not applied, the estimated optimal vitamin D fortification level of 209 IU/100 g would produce a deficiency prevalence of 96.3% rather than the target prevalence of 50%.

It should be noted that in the case of folic acid, vitamin D, and other nutrients evaluated in this study, estimated optimal fortification levels for adults are generally high in comparison with reference guidelines. Such levels would not necessarily be feasible for implementation given concerns around palatability, food formulation, food safety, and cost, even in the absence of appropriate overage. These concerns are explicitly accounted for in the development of published fortification guidelines, while they are explicitly ignored in the estimation of optimal levels which are only informed by the observed distribution of nutrient intakes and nutrient requirements. Estimated optimal levels do, however, indicate the potential degree to which published guidelines may prove or fail to be effective in a given setting, as well as the direction and degree to which such guidelines should be adjusted - within the range of concentrations allowed by palatability, formulation, safety, and cost considerations - prior to their implementation. Estimated optimal levels should therefore be interpreted as a means of guidance with which to empirically tailor published guidelines to local circumstances.

We find that the range of estimated overage factors for wheat flour across seasons and subgroups in Mongolia appeared to be reasonably narrow, suggesting that while optimal fortification levels may vary significantly from one subgroup to the next, a particular overage factor will be reasonably effective in curbing processing, storage, and cooking losses across the population.

Strengths and limitations

This study was strengthened by a rigorous baseline dietary assessment incorporating local and empirical information on recipes, dish yields, and food composition from a national sample including representation of geographic and seasonal extremes as well as urban and rural subgroups. Modeling was highly detailed and considered fortification of three vehicles separately and simultaneously, the sub-national distribution of the capacity of milk to be industrially fortified, a range of possible fortification levels suggested by national, regional, and international guidelines (and estimation of season- and subgroup-specific optimal fortification levels for comparison), estimates of fortificant stability during food processing, storage, and cooking informed by local flour consumption patterns, and estimates of nutrient bioavailability informed by food and nutrient consumption patterns. These aspects render more confidence in the accuracy of our projects as to the effectiveness of fortification, and provide a sizeable range of local guidelines to consider with respect to fortificants, food vehicles, and overage.

A limitation of this study was the need to pool data across national provinces in order to produce baseline and post-fortification estimates of nutrient intake and intake deficiency prevalence with reasonable statistical power, limiting the geographical disaggregation of our results to urban and rural areas. A second limitation was the lack of dietary data available for infants and children, pregnant and lactating women, and the elderly, making it impossible to model fortification's effectiveness in these target groups. This must be considered in setting fortification levels, given these groups' unique nutritional requirements and food consumption patterns. For example, while intake deficiencies of iron and zinc were found to be less common than that of other nutrients among adults in the current study, iron and zinc may be the most severely intake deficient and biochemically deficient micronutrients, respectively, among Mongolian young children (Lander 2008, 2010). An unmet need for nutrition research in Mongolia is periodic national surveillance of food and nutrient intake, particularly among higher-risk target groups, which should be prioritized for the purpose of updating fortification levels and informing complimentary national nutrition policies. An example of the potential importance of updating such levels is the case of industrially-produced milk, fortification of which was projected to be less effective than that of flour or oil due to its non-consumption in rural areas and low penetration in urban areas, while suggested overage for milk fortification was influenced by the fact that most milk in Mongolia is boiled as part of milk teas and milk-based soups, leading to vitamin degradation; significant changes in the urban-rural distribution of industrial milk production, consumption, or in-home culinary practices would therefore render our models outdated. A resourceful means of dietary surveillance in Mongolia may involve application of the country's series of frequent household consumption and expenditure surveys (NSO 2014). These surveys contain extensive information on household food consumption which may be analyzed for trends in household food vehicle or nutrient consumption, or supplemented with modules for assessing intra-household distribution of vehicles and nutrients (Fiedler 2013).

Conclusions for Mongolia

In conclusion, this analysis supports a policy of large-scale industrial fortification of wheat flour and wheat flour products, edible oil, and milk with iron, thiamin, riboflavin, folic acid, and vitamins A, D, and E in Mongolia. Flour fortification levels for thiamin and folate may be drawn from national guidelines published by the Mongolian University of Science and Technology, riboflavin from half the national guideline's level, and iron at the level published by the World Health Organization for countries consuming 300+ g/day of wheat flour. National guidelines for fortification of wheat flour and edible oil with vitamins A and E should be developed based on WHO and DSM international guidelines, respectively, incorporating local cost and technical considerations. National guidelines for industrial fortification of vitamins A and D in milk and vitamin D in wheat flour should also be developed by adapting guidance from existing regional standards published by the USDA and GSO, respectively. The value of zinc, niacin, and vitamin B12 fortification is not supported by this analysis for adults, however the merits of industrial fortification and alternative or simultaneous targeted strategies for delivering these nutrients should still be considered given the potentially significant health benefits for target groups not considered in this study, and weighed against the possible risks of supplying the general population with more nutrients than it may require (this also applies to thiamin, riboflavin, folic acid, and vitamins A, D, and E). While over-sufficiency is not necessarily (nor intended to be) indicative of toxicity, it bears noting that the long-term effects of potentially excessive intake of most nutrients are not well understood, and have in some cases been implicated in increased risk of disease below or in the absence of upper limits.

Ultimately, selected fortification levels must satisfy a variety of constraints to implementation, including cultural acceptability and cost of fortification, market readiness, and capacity to implement, inspect, monitor, evaluate, and sustain a fortification program; these concerns may be addressed as appropriate by social marketing, cost effectiveness and market research, and needs assessment of the country's relevant technical and regulatory infrastructure (Allen 2004). To ensure the effectiveness of industrial fortification in Mongolia, fortification should be mandatory, and overage for processing, storage, and cooking should be incorporated in policy guidance to accompany legislation and new or updated premix specifications. The penetration and specificity with which industrial fortification affects nutrient intake in different groups may be enhanced by considering additional potential fortification vehicles in the future. More generally, as industrial fortification is not meant to address all micronutrient intake deficiencies but rather provide a foundation for healthy nutrition, fortification itself should be accompanied by other short- and long-term supply- and demand-side approaches as part of the national nutrition strategy, including home fortification and supplementation, dietary modification, agriculture and biofortification, and economic, trade, and procurement policies geared toward diversifying the Mongolian food supply.

Conclusions for other countries

- While WHO food fortification guidelines state that “possession of quantitative food and nutrient intake data is a prerequisite for any food fortification programme” and for projecting such a program’s impact (Allen 2004), the WHO also provides recommendations on wheat and maize flour fortification based on an expert review and consensus (WHO 2009a). Based on our analysis, neither estimated optimal fortification levels nor those drawn from international guidelines (including those tailored to different strata of per-capita vehicle availability) should necessarily be interpreted as superior. Modeling studies such as the one described in this paper can be useful for determining the extent to which published guidelines may benefit from adjustment prior to their application in a particular country.
- Within countries, there may be significant variation in the effectiveness of fortification across population subgroups and seasons (for example, between subgroups defined by sex, locality, and season). Such differences should be considered during the collection of baseline dietary data for setting national fortification levels, the setting of these levels themselves, and monitoring an extant fortification program.
- In setting fortification levels, it is important to incorporate overage for processing, storage, and cooking when setting fortification levels. Otherwise, the effectiveness of fortification may be diminished considerably, particularly in the case of less stable vitamins.
- Considering multiple fortification vehicles for delivery of the same and different nutrients is prudent, as it may increase the overall effectiveness of fortification and allow natural variation in population dietary patterns to be exploited for more effective targeting of intake deficiencies in different subgroups.

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Appendix

Appendix A: Details on nutritional analysis of diet

Empirical recipes and dish yields (FAO 2013) were generated for complex dishes by averaging information on their raw ingredient and cooked dish masses across all instances in which accurate measurement of these masses was feasible, applying ingredient yield factors (Matthews 1975, Bognár 2002) as needed when a dish yield could not be calculated. Nutrient composition of ingredients, single-ingredient food items, and complex dishes were compiled using a combination of unpublished locally-analyzed food composition data from the Mongolian University of Science and Technology and Mongolian Public Health Institute, food composition data from the United States and Germany (Hartmann 2005, Haytowitz 2011), and entries from a combination of international reference tables previously compiled as part of a food composition table for Mongolian children (Lander 2010). Where applicable, dish yield and nutrient retention factors (Bognár 2002, NDL 2007, Showell 2012) were applied to calculate nutrient concentrations in cooked foods, as were adjustments for rendering compatible nutrient concentrations in borrowed and source food composition data with different moisture and fat contents (FAO 2013).

Appendix B: Details on statistical programs

In this study, the Statistical Program to Assess Dietary Exposure (SPADE) (Dekkers 2014) was used to correct repeated measurements of wheat flour, edible oil, and milk intake for within-person variance in order to estimate medians of the usual intake distributions of these fortification vehicles in different seasons and subgroups defined by urban/rural locality and sex. For this purpose, SPADE’s 1-part model was used, which is based on an earlier model by Waijers and colleagues (Waijers 2006) and is appropriate for dietary components consumed on a habitual basis (i.e. non-zero on almost every person-day of observation). In the 1-part model, only intake amounts are modeled rather than additionally modeling intake frequencies.

The 1-part model involves 3 steps as summarized by Dekkers and colleagues: Box-Cox transformation of observed daily intakes to obtain a normally-distributed intake distribution; modeling of transformed intakes as a function of age to estimate within- and between-person variance components with which to attenuate the variance of the observed intake distribution (an age-independent model is also allowed, but was not used in this study as there was no reason to do so; however, all ages were aggregated in presenting results of fortification vehicle intake); and back-transformation of the usual intake distribution to the response scale.

SPADE models may be run for males, females, or both sexes (in this study, males and females were modeled separately). SPADE allows inclusion of survey weights and population numbers to better represent the target population, and estimation of bootstrap confidence intervals to quantify uncertainty in the usual intake distributions (all of these features were used in this study).

The Intake Monitoring, Assessment, and Planning Program (IMAPP) (WHO 2010) was used to project usual distributions of nutrient intake and the prevalence of intake deficiency and oversufficiency in different seasons and subgroups defined by urban/rural locality and sex, both before and after industrial fortification. Rather than model intake as a function of age as in SPADE, different IMAPP models are run for different age groups (in this study, age groups of adults were pooled given the homogeneity of their nutrient requirements). IMAPP implements the Iowa State University (ISU) method developed by Nusser and colleagues (Nusser 1996) and is an extension of the PC Software for Intake Distribution Estimation (PC-SIDE) engine.

The procedure involves the following steps as part of the PC-SIDE algorithm, as summarized by Nusser: adjustment of observed intake distributions for nuisance effects which may influence daily intake (in this study, the effect of day of the week was already accounted for by the survey weights used); adjustment of observed intakes so that they have a mean and variance of the first sample days' (as measurement of this day's intake is considered to be most accurate); application of survey weights; transformation of the observed intake distribution using power and grafted polynomial functions to achieve normality; estimation of the transformed distribution's variance components and estimation in turn of the parameters of the usual intake distribution; and back-transformation of the usual intake distribution on the response scale.

In IMAPP, the PC-SIDE procedure is preceded by adjustment of nutrient intake on each person-day according to the daily intake of fortification vehicles and the concentration of fortificant to be added to each. Alternatively, the software can estimate the minimum fortificant concentration necessary to achieve a subgroup-specific prevalence of intake deficiency, by running a range of models bounded by minimum and maximum fortification levels until a desired prevalence is reached. After running each model, IMAPP applies the EAR cut-point method (IOM 2000) to the usual intake distributions to estimate the prevalence of deficiency and over-sufficiency (in this study, age group- and sex-specific cutoffs were drawn from IOM 2014); in the case of iron, the EAR cut-point method is inappropriate given iron's lognormal requirement distribution in premenopausal women and therefore a full-probability approach is used instead (IOM 2000).

Appendix C: Assumptions of fortification models

In modeling the effects of fortification, the following simplifying assumptions were made:

- A negligible fraction of wheat flour, edible oil, and milk is currently subject to voluntary industrial fortification in Mongolia (personal communication, June 2017: Enkhbileg G. (Executive Director of Dairy Unit, APU Company), Blüthner A (Director of Food Fortification and Partnerships, BASF), Leufgen A (General Manager, Stern Ingredients); this fraction was therefore not accounted for by the food composition data used in this study.

- Milk consumed in rural areas is entirely produced at home rather than industrially-processed, as supported by prevailing food consumption patterns in Mongolia (FAO 2007); rural areas are therefore impenetrable to industrial milk fortification.
- Actual concentrations of micronutrients present in fortification vehicles are equal to those stipulated by fortification and overage guidelines (described in subsequent sections). The validity of this assumption will depend on the closeness with which Mongolia's upcoming fortification program is inspected and monitored.
- Industrial milk fortification only affects non-fermented liquid, dry, and condensed milk, and does not appreciably affect micronutrient concentrations in dairy products, including butter, cheese, cream, curds, and yogurt); conversely, industrial wheat flour fortification does affect products composed of wheat flour. While the validity of these assumptions will depend on technical considerations and the expansiveness of upcoming fortification legislation in Mongolia, their practicality is supported by inspection of national food composition data from the United States, a country in which fortification of wheat flour with B vitamins and iron is mandatory and fortification of milk with vitamin D is widespread, and in which wheat flour products are found to be rich in fortified nutrients while dairy products contain minimal vitamin D (Haytowitz 2011).
- Concentrations of fortificants found in wheat flour, edible oil, and milk imported to Mongolia are equal to those found in vehicles produced in and subject to fortification in Mongolia. The validity of this assumption will depend on the design and impact of future trade policy in Mongolia. Analysis of recent food balance data shows that wheat flour and flour products, and milk imports account for 11.0% and 1.7% of domestic supply, respectively, while 19.1% and 0% of imported flour and milk originates from countries known to fortify these vehicles (at least for domestic consumption) (FAO 2017). Furthermore, 100% of edible oil consumed in Mongolia is imported, some of which is fortified. In order for vehicles to meet Mongolian guidelines, it will be necessary for Mongolia to harmonize its international trade and domestic fortification guidelines by mandating that imported flour (particularly from Russia, its primary importer) and edible oil (which originates from many countries) are appropriately fortified.

Appendix D: Details on estimation of fortificant losses and overage factors

For edible oil and milk, processing and storage losses were estimated using nutrient- and vehicle-specific nutrient stability factors (DSM 2017b), cooking losses were estimated using nutrient- and vehicle-specific nutrient retention factors (Bognár 2002, Showell 2012), and total losses were estimated by multiplying the former by the latter, being careful not to multiply factors which accounted for redundant steps in food preparation. Collected diet records did not consistently allow sufficient granularity to distinguish between boiled and un-boiled forms of milk, in part because the vast majority of consumed milk was observed to be boiled; for the purpose of assigning nutrient losses, all consumed liquid, unfermented milk was therefore assumed to have been boiled, an assumption not expected to materially affect the results of fortification models. Because the stability of nutrients in flour products is dependent on the type of product being considered (as is less the case with edible oil- and milk-containing products), and because different products are consumed in different proportions from one subgroup and season to another, nutrient-specific processing, storage, and cooking losses for flour were summarized for each of the 8 season-subgroups by assigning losses separately to each flour-product and taking an average weighted according to the observed mean fraction of total flour intake contributed by different flour products across all study participants in the season-subgroup.

Nutrient-specific overage factors were calculated for each food vehicle by taking the reciprocal of predicted nutrient losses attributable both to cooking alone and to processing, storage, and cooking, therefore providing overage factors for both processing and storage, and processing, storage, and cooking, respectively (Table S2.1). In the case of flour, summer and winter means of subgroup-specific overage factors, weighted according to the size of each subgroup, were then estimated for each combination of nutrient, overage level, and season. An annualized average of summer and winter mean flour overage factors for each nutrient and overage level was calculated and tabulated along with the minimum and maximum of the 8 season-subgroup specific overage used to calculate each. For all nutrients, the range of estimated flour overage factors across season-subgroups is reasonably close to the average of weighted summer and winter means; the narrowest and widest ranges for processing, storage, and cooking are 1.418-1.448 (vitamin A) and 1.638-1.787 (thiamin), respectively.

Appendix E: Policy Brief

Despite steady and impressive progress in curbing wasting, stunting, and low birth weight, a persisting lack of dietary diversity underlies a high prevalence of multiple micronutrient deficiencies in Mongolia. In a nationwide, bi-annual survey of 320 healthy adults living in urban and rural areas of 7 national provinces and Ulaanbaatar, we found intake deficiencies of thiamin, folate, and vitamins A, D, and E to be highly prevalent, particularly among women. Micronutrient deficiencies in women of reproductive age pose a threat to their health as well as the health of their offspring during pregnancy and nursing, leading to potentially severe and permanent physical and cognitive deficits.

A large body of international evidence has demonstrated industrial fortification of staple foods with micronutrients, particularly when mandated by law and subject to appropriate inspection and monitoring, to be an effective, cost-saving, and safe strategy for improving nutrition in populations. At present, the only example of mandatory fortification in Mongolia is that of salt with iodine, which has proven to be an effective public health measure against goiter since its commencement in 1996.

Using data from our survey, we modeled the effects of different wheat flour, edible oil, and milk fortification guidelines on the prevalence of intake deficiency and over-sufficiency of 10 vitamins and minerals among 4 subpopulations of Mongolian adults in summer and winter, summarized in Table S2.2. Results of our models indicate that flour fortification would be effective in reducing intake deficiencies of thiamin and folate, while the marginal benefit of fortification with iron and riboflavin would be smaller in part given these nutrients' higher baseline consumption, and the benefit of fortification with zinc, niacin, and vitamin B12 is uncertain without data from children. Fortification of flour, oil, and milk with vitamins A, D, and E at levels suggested by international guidelines would substantially reduce vitamin A intake deficiency and would increase vitamin D intake considerably, with the greatest benefits elicited by wheat flour fortification and smaller benefits by additionally fortifying oil and milk.

These results strongly support the implementation of mandatory industrial fortification of wheat flour, edible oil, and milk with multiple micronutrients in Mongolia. We therefore provide the following policy guidance to assist the design and implementation of Mongolia's national industrial fortification program, a bill for which is currently under legislative review by the Parliament:

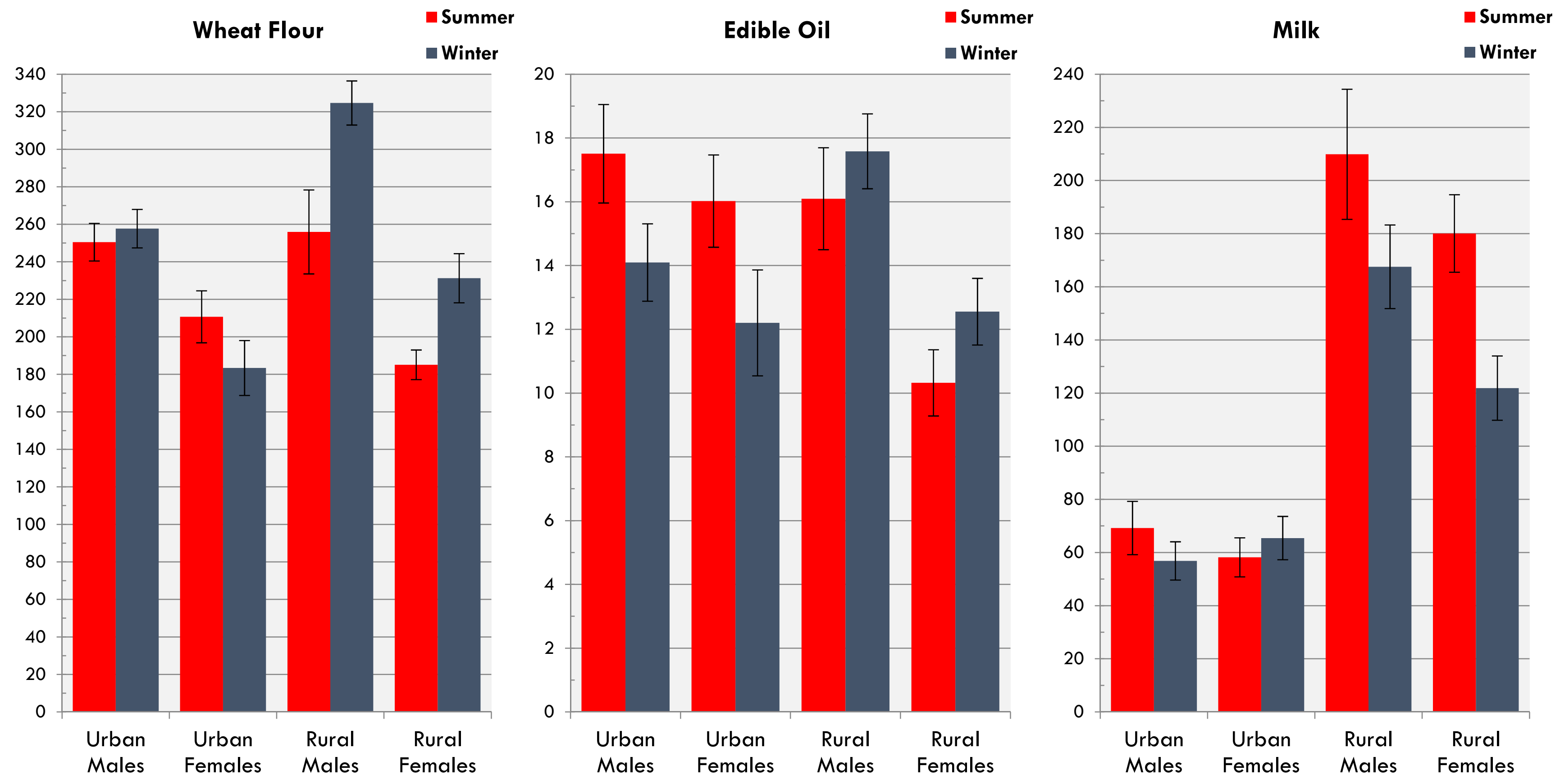
- Fortification of wheat flour with thiamin, and folate is recommended at levels suggested by national guidelines published by the University of Science and Technology, riboflavin at half this level, and iron at the level published by the World Health Organization for countries consuming 300+ g/day of wheat flour. Overage should be applied to compensate for nutrient losses during food processing, storage, and cooking.

- Fortification of wheat flour and milk with vitamins A and D, and oil with vitamins A, D, and E is recommended. National guidelines for mandatory fortification of wheat flour and edible oil with vitamins A and E should be developed based on World Health Organization and DSM international guidelines, respectively, incorporating local cost and technical considerations. National guidelines for mandatory fortification of vitamins A and D in milk and vitamin D in wheat flour should also be developed by adapting initial guidance from existing regional standards published by the United States Department of Agriculture and Gulf Cooperation Council Standardization Organization, respectively.

- Fortification of wheat flour with zinc, niacin, and vitamin B12, while not supported by this analysis for adults, may prove beneficial for children. This should be affirmed by collection and analysis of food and nutrient intake data from children. Implementing national dietary surveillance should be a priority for monitoring and evaluation of fortification, and for public health in general in Mongolia.

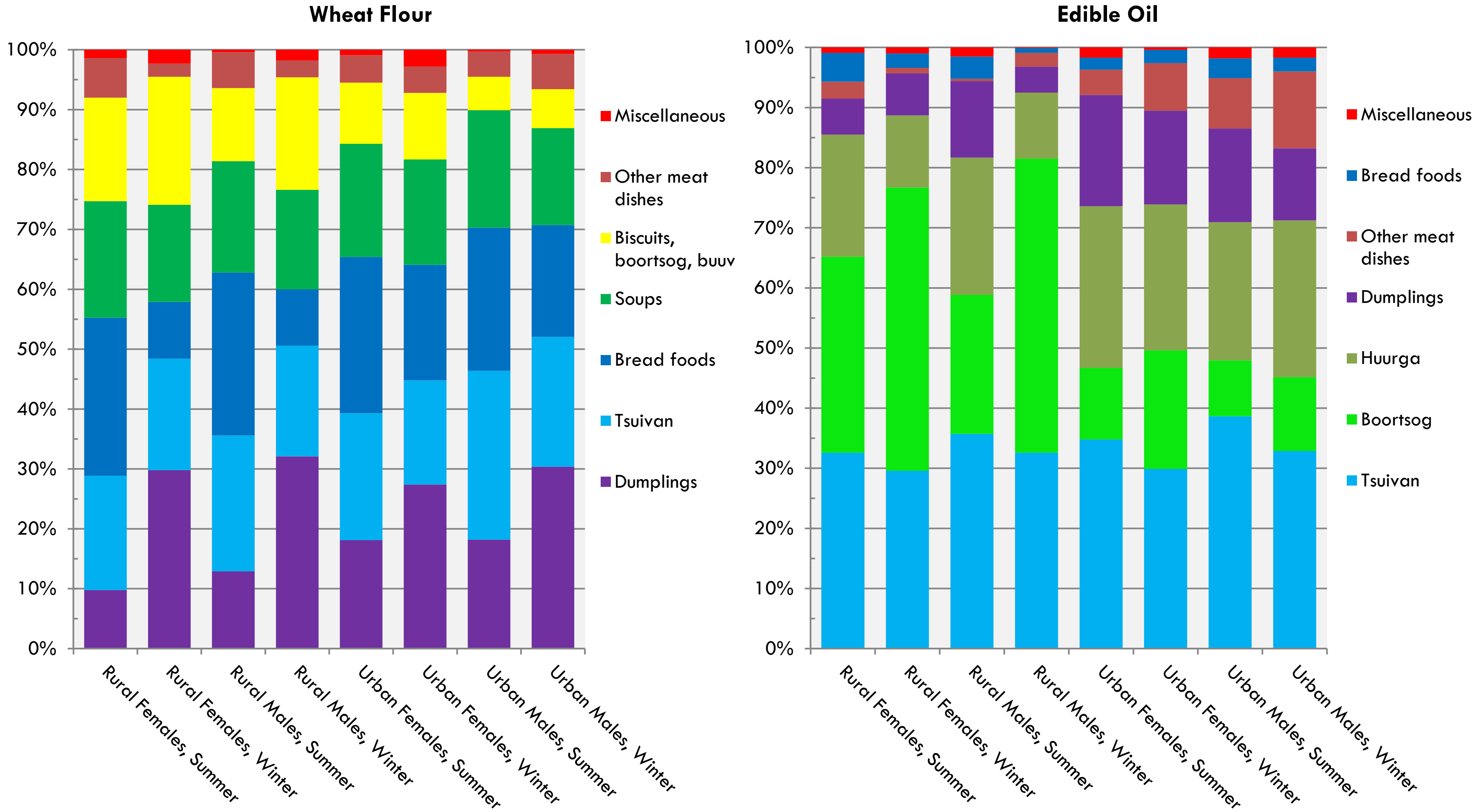
Fortification should be accompanied by continued development of other short- and long-term supply- and demand-side approaches as part of the national nutrition strategy, including home fortification and supplementation, dietary modification, agriculture and biofortification, and economic, trade, and procurement policies geared toward diversifying the national food supply.s

Figure S2.1: Median consumption (g/day) of wheat flour, edible oil, and milk among different population subgroups of Mongolian adults in summer and winter



Error bars span 95% confidence intervals estimated using 1000 bootstrap samples. Medians and associated confidence intervals were estimated using the Statistical Program to Assess Dietary Exposure (SPADE) (Dekkers 2014). Milk includes that which is both fortifiable (industrially-processed) and un-fortifiable (produced at home).

Figure S2.2: Percentage contribution of consumed food groups to wheat flour and edible oil consumption among different subgroups of Mongolian adults in summer and winter



Boortsog: a deep-fried wheat-flour snack similar to a donut; buuv: a broad category of baked wheat-flour biscuits; huurga: a broad category of meat-based dishes made with various stir-fried and steamed ingredients; tsuivan: a dish of steamed wheat-flour noodles and stir-fried meat. Bread foods include plain bread and bread with toppings or condiments. Dumplings include steamed, fried, and boiled dumplings.

Figure S2.3: Prevalence of vitamin A intake deficiency (%<EAR) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour, oil, and milk fortification and overage guidelines (urban areas): http://rpubs.com/sbromage/MonFortMod_VitA_EAR)

Figure S2.4: Prevalence of vitamin A over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour, oil, and milk fortification and overage guidelines (urban areas): http://rpubs.com/sbromage/MonFortMod_VitA_UL)

Figure S2.5: Prevalence of vitamin D intake deficiency (%<EAR) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour, oil, and milk fortification and overage guidelines (urban areas): (http://rpubs.com/sbromage/MonFortMod_VitD_EAR)

Figure S2.6: Median intake of vitamin D (IU/day) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour, oil, and milk fortification and overage guidelines (urban areas): http://rpubs.com/sbromage/MonFortMod_VitD_IU)

Figures S2.3-2.5 (available online: http://rpubs.com/sbromage) show the percentage of each urban subgroup's vitamin A or D intake lying below the subgroup-specific estimated average requirement (EAR) or above its upper limit (UL), respectively, at baseline (Level 0) and projected under different fortification and overage guidelines; Figure S2.6 shows baseline and projected median intake of vitamin D (IU/day). The x, y, and z axes span a range of flour, oil, and milk fortificant concentrations (in units of fortificant per 100 grams of vehicle), respectively, which correspond to the range of modeled levels. Shading indicates the extent of projected intake deficiency or over-sufficiency, or the magnitude of projected median intake (lowest value: dark purple; highest value: bright yellow). See Methods and Table 2.1 for description of levels and references. When viewing a graph, place the cursor over each point to see more information, double-click legend items to cycle through population subgroups, click and drag to rotate the graph, and use the mouse wheel to zoom in and out. Note: graphs are only interpretable when one legend item is active at a time. Abbreviations: IU (international unit; 40 IU = 1 μg), PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses).

Table S2.1: Mean estimated overage factors for industrial fortification in Mongolia

	Overage Guideline:	**PS**		**PSC**	
Vehicle	**Nutrient**	**Mean**	**Range**	**Mean**	**Range**
Flour	Iron and Zinc	1.053			
	Vitamin A	1.372	1.341-1.392	1.436	1.418-1.448
	Vitamin D	1.279	1.253-1.294	1.279	1.253-1.294
	Thiamin	1.482	1.426-1.508	1.737	1.638-1.787
	Riboflavin	1.322	1.292-1.337	1.421	1.371-1.440
	Niacin	1.239	1.220-1.249	1.331	1.306-1.344
	Folate	1.447	1.383-1.486	1.889	1.841-1.910
	Vitamin B12	1.239	1.221-1.249		
Oil	Vitamins A and D	1.176		1.322	
	Vitamin E	1.429		2.198	
Milk	Vitamins A and D	1.429			

Values represent ranges and survey-weighted means of 8 season- and subgroup-specific overage factors (factors by which fortification levels should be multiplied to compensate for losses) defined as the reciprocal of predicted nutrient losses due to processing and storage (PS) or processing, storage, and cooking (PSC). See Methods for derivation of nutrient losses and references. PSC means and ranges are omitted for iron, zinc, and B12 in flour and vitamins A and D in milk due to negligible cooking losses. PS range for iron in flour and vitamins A and D in milk are omitted due to invariant processing and storage losses observed across flour and milk products, respectively. PS and PSC ranges are omitted for vitamins A, D, and E in oil due to invariant processing, storage, and cooking losses observed across oil-containing products.

Table S2.2: Summary table of prevalence of vitamin and mineral deficiencies (%<EAR) among Mongolian adults in summer and winter at baseline and projected under different fortification guidelines

				Baseline %<EAR		Post-Fortification %<EAR	
Nutrient	**Fortificant**	**Vehicle**	**Level (per 100g)**	**Summer**	**Winter**	**Summer**	**Winter**
Iron	Ferrous fumarate	Flour	2.0 mg	9	10	4	5
Zinc	Zinc Oxide		N/A	1	1	N.S.	N.S.
Thiamin	Thiamin mononitrate		0.4 mg	54	68	3	7
Riboflavin	Riboflavin		0.2 mg	8	7	1	2
Niacin	Nicotinamide		N/A	7	8	N.S.	N.S.
Folate	Folic acid		115 µg	99	97	6	9
Vitamin B12	Cyanocoabalamin		N/A	0	0	N.S.	N.S.
Vitamin A	Retinol palmintate	Flour	117 µg	53	59	9	17
		Oil	900 µg				
		Milk	62 µg				
Vitamin D	Cholecalciferol	Flour	55 IU	100	100	97	99
		Oil	300 IU	(42 IU/day)	(28 IU/day)	(213 IU/day)	(202 IU/day)
		Milk	42 IU				
Vitamin E	Alpha tocopherol	Oil	10.7 mg	99	99	95	96

Baseline and post-fortification %<EAR (estimated average requirement) represents the percentage of the population whose nutrient intake is deficient at baseline or projected to be deficient under fortification at the specified level. For vitamin D, baseline and projected median intake (in IU/day) are also provided. Statistics are weighted for the national population and projections assume fortification overage for food processing, storage, and cooking. N.S. (fortification not supported): evidence from this analysis does not support fortification of these nutrients for Mongolian adults, based on either low baseline prevalence of intake deficiency or moderate projected post-fortification prevalence of over-sufficiency; research is warranted to determine effectiveness of fortifying these nutrients among children. IU: international unit (40 IU = 1 µg).

Table S2.3: Prevalence of thiamin, riboflavin, folate, and vitamin B12 intake deficiency (%<EAR) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour fortification and overage guidelines

		Subgroup:	**Rural Females**		**Rural Males**		**Urban Females**		**Urban Males**	
Nutrient	**Fortification Level**	**Overage Guideline**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Thiamin	0	None	65.0	81.9	36.2	53.4	58.4	73.5	53.3	62.5
	1	None	29.7	43.9	16.1	9.6	31.8	48.9	22.3	31.9
		PS	18.8	29.8	10.9	3.8	22.6	38.7	12.9	20.2
		PSC	14.3	23.2	9.2	2.4	19.0	34.1	9.5	15.0
	2	None	8.5	17.8	7.1	1.4	15.8	30.5	7.1	11.9
		PS	2.3	7.5	3.6	0.2	8.2	18.8	1.9	4.0
		PSC	1.2	4.4	2.6	0.1	5.8	14.7	1.0	2.1
	3	None	1.8	6.8	3.4	0.2	8.1	18.8	1.9	4.0
		PS	0.2	2.0	1.4	0.0	3.1	9.5	0.3	0.7
		PSC	0.0	1.0	1.0	0.0	2.0	6.9	0.1	0.3
	4	None	0.3	2.7	1.7	0.0	4.2	11.8	0.5	1.2
		PS	0.0	0.6	0.6	0.0	1.3	5.3	0.0	0.2
		PSC	0.0	0.3	0.4	0.0	0.8	3.5	0.0	0.0
Riboflavin	0	None	3.4	10.9	5.3	0.6	8.0	11.4	11.2	4.8
	1	None	0.6	2.3	1.7	0.0	3.3	5.9	3.4	1.3
		PS	0.4	1.4	1.3	0.0	2.4	4.9	2.4	0.8
		PSC	0.3	1.3	1.2	0.0	2.3	4.6	2.1	0.6
	2	None	0.1	0.5	0.8	0.0	1.4	3.3	1.0	0.2
		PS	0.0	0.2	0.5	0.0	0.9	2.0	0.5	0.0
		PSC	0.0	0.2	0.5	0.0	0.8	1.8	0.5	0.0
	3	None	0.0	0.1	0.4	0.0	0.7	1.7	0.4	0.0
		PS	0.0	0.0	0.3	0.0	0.4	1.0	0.1	0.0
		PSC	0.0	0.0	0.2	0.0	0.3	0.9	0.1	0.0
	4	None	0.0	0.0	0.3	0.0	0.4	1.0	0.1	0.0
		PS	0.0	0.0	0.2	0.0	0.2	0.6	0.0	0.0
		PSC	0.0	0.0	0.2	0.0	0.1	0.5	0.0	0.0
Folate	0	None	100.0	99.3	97.1	97.1	99.7	99.0	98.0	94.4
	1	None	83.1	54.4	31.3	11.0	55.4	67.8	24.7	26.1
		PS	41.0	29.7	13.9	2.2	30.9	46.0	5.0	6.5
		PSC	12.3	12.4	6.3	0.3	18.7	29.4	1.0	1.4
	2	None	70.6	43.6	24.0	5.9	46.6	60.3	15.3	16.3
		PS	22.3	20.4	9.4	1.0	23.4	37.2	2.2	3.5
		PSC	3.9	7.4	4.3	0.1	13.1	22.1	0.3	0.6
	3	None	55.5	34.2	18.2	3.1	38.9	52.9	9.2	10.6
		PS	10.9	14.3	6.4	0.4	17.8	29.9	1.0	1.6
		PSC	1.2	4.4	2.8	0.0	9.3	16.8	0.1	0.3
	4	None	35.5	24.2	12.8	1.3	30.4	44.0	4.5	5.5
		PS	3.3	8.5	4.0	0.2	12.2	22.4	0.3	0.6
		PSC	0.2	2.4	1.5	0.0	5.8	11.6	0.0	0.1
Vitamin B12	0	None	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
	1	None	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	None	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	3	None	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4	None	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Values represent the percentage of each subgroup's nutrient intake lying below the subgroup-specific estimated average requirement (EAR) at baseline (Level 0) and projected under different fortification and overage guidelines. Shading indicates the extent of projected intake deficiency (0%: green; 50%: yellow; 100%: red). See Methods and Table 2.1 for description of levels and references. Abbreviations: PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses). Vitamin B12 losses in cooking flour products are negligible, therefore PSC overage for vitamin B12 is not modeled.

Table S2.4: Prevalence of iron, zinc, vitamin E, and niacin intake deficiency (%<EAR) and over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour or oil fortification and overage guidelines

		Subgroup:	Rural Females				Rural Males				Urban Females				Urban Males			
		Season:	Summer		Winter		Summer		Winter		Summer		Winter		Summer		Winter	
Nutrient (Vehicle)	**Fortification Level**	**Overage Guideline**	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL
Iron (Flour)	0	None	18.7	0.0	10.6	0.0	0.5	0.0	0.0	0.0	16.8	0.0	22.2	0.0	0.2	0.0	0.0	0.3
	1	None	7.5	0.0	3.6	0.0	0.0	0.0	0.0	0.0	7.8	0.0	11.5	0.0	0.0	0.0	0.0	0.3
		PS	7.3	0.0	3.5	0.0	0.0	1.3	0.0	0.3	7.5	0.1	11.1	0.0	0.0	0.0	0.0	1.2
	2	None	6.3	0.0	3.0	0.0	0.0	1.4	0.0	0.4	6.9	0.1	10.3	0.1	0.0	0.0	0.0	1.3
		PS	5.7	0.0	2.9	0.0	0.0	1.8	0.0	0.5	6.8	0.2	9.8	0.1	0.0	0.1	0.0	1.5
	3	None	5.1	0.0	2.3	0.0	0.0	2.0	0.0	0.6	6.2	0.2	9.5	0.1	0.0	0.1	0.0	1.6
		PS	4.7	0.0	2.1	0.0	0.0	2.5	0.0	0.8	6.0	0.2	8.5	0.2	0.0	0.2	0.0	1.9
	4	None	4.1	0.0	2.0	0.0	0.0	2.7	0.0	0.9	5.6	0.3	8.2	0.2	0.0	0.2	0.0	2.3
		PS	3.9	0.0	1.9	0.0	0.0	3.2	0.0	1.2	5.1	0.3	8.0	0.2	0.0	0.3	0.0	2.7
Zinc (Flour)	0	None	1.4	0.0	1.9	0.0	0.8	3.7	0.5	1.6	2.1	0.4	0.3	0.3	0.5	0.4	0.8	2.9
	1	None	0.0	0.0	0.1	1.1	0.1	14.2	0.0	23.2	0.2	3.3	0.0	0.4	0.0	7.9	0.0	14.2
		PS	0.0	0.0	0.1	1.3	0.0	15.6	0.0	25.4	0.2	3.8	0.0	0.5	0.0	9.0	0.0	15.5
	2	None	0.0	0.0	0.0	1.6	0.0	17.1	0.0	27.9	0.2	4.3	0.0	0.6	0.0	10.4	0.0	17.0
		PS	0.0	0.0	0.0	2.0	0.0	18.8	0.0	30.6	0.1	4.9	0.0	0.8	0.0	11.9	0.0	18.4
	3	None	0.0	0.0	0.0	2.4	0.0	20.6	0.0	33.2	0.1	5.5	0.0	1.0	0.0	13.5	0.0	20.0
		PS	0.0	0.0	0.0	2.9	0.0	22.4	0.0	36.2	0.1	6.3	0.0	1.3	0.0	15.3	0.0	21.9
	4	None	0.0	0.0	0.0	3.3	0.0	24.0	0.0	38.5	0.1	6.8	0.0	1.5	0.0	16.8	0.0	23.2
		PS	0.0	0.0	0.0	3.9	0.0	26.4	0.0	42.0	0.1	7.8	0.0	1.8	0.0	19.1	0.0	25.4

Table S2.4 (continued)

		Subgroup:	Rural Females				Rural Males				Urban Females				Urban Males			
		Season:	Summer		Winter		Summer		Winter		Summer		Winter		Summer		Winter	
Nutrient (Vehicle)	Fortification Level	Overage Guideline	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL
Vitamin E (Oil)	0	None	100.0	0.0	99.7	0.0	98.8	0.0	99.8	0.0	98.8	0.0	99.0	0.0	100.0	0.0	99.5	0.0
	1	None	100.0	0.0	99.2	0.0	96.3	0.0	98.6	0.0	97.8	0.0	98.0	0.0	99.0	0.0	98.1	0.0
		PS	100.0	0.0	99.1	0.0	95.8	0.0	98.2	0.0	97.5	0.0	97.8	0.0	98.4	0.0	97.7	0.0
		PSC	100.0	0.0	99.0	0.0	95.2	0.0	97.8	0.0	97.2	0.0	97.6	0.0	98.0	0.0	97.4	0.0
	2	None	100.0	0.0	98.7	0.0	94.0	0.0	96.6	0.0	96.4	0.0	97.0	0.0	96.6	0.0	96.5	0.0
		PS	100.0	0.0	98.4	0.0	92.9	0.0	95.2	0.0	95.7	0.0	96.5	0.0	94.9	0.0	95.6	0.0
		PSC	100.0	0.0	98.1	0.0	91.8	0.0	93.6	0.0	95.0	0.0	96.1	0.0	93.8	0.0	94.7	0.0
	3	None	100.0	0.0	98.0	0.0	91.1	0.0	92.8	0.0	94.7	0.0	95.9	0.0	93.0	0.0	94.2	0.0
		PS	99.9	0.0	97.4	0.0	89.1	0.0	89.9	0.0	93.1	0.0	95.0	0.0	89.2	0.0	91.9	0.0
		PSC	99.8	0.0	96.9	0.0	87.1	0.0	86.8	0.0	91.5	0.0	94.2	0.0	85.4	0.0	90.0	0.0
	4	None	99.8	0.0	97.0	0.0	87.7	0.0	87.7	0.0	91.9	0.0	94.5	0.0	86.5	0.0	90.5	0.0
		PS	99.7	0.0	96.1	0.0	84.6	0.0	82.8	0.0	89.2	0.0	93.2	0.0	79.8	0.0	87.6	0.0
		PSC	99.4	0.0	95.1	0.0	81.4	0.0	77.9	0.0	86.7	0.0	92.0	0.0	72.5	0.0	84.8	0.0
Niacin (Flour)	0	None	11.6	0.0	13.0	0.1	3.4	6.1	0.5	15.4	10.9	1.2	13.4	0.2	2.2	6.8	2.0	12.7
	1	None	3.9	0.0	4.9	0.5	1.6	14.8	0.0	28.0	5.6	3.0	7.6	0.6	0.7	13.7	0.7	20.0
		PS	3.0	0.0	3.9	0.6	1.4	17.4	0.0	31.6	4.7	3.7	6.7	0.8	0.5	15.4	0.5	21.9
		PSC	2.8	0.0	3.5	0.6	1.3	18.4	0.0	33.2	4.5	4.0	6.4	0.9	0.5	16.3	0.5	22.8
	2	None	1.0	0.0	1.4	1.2	0.8	26.5	0.0	45.4	3.1	6.6	4.4	2.0	0.2	23.2	0.3	29.1
		PS	0.6	0.2	0.9	2.1	0.6	32.4	0.0	53.8	2.3	9.0	3.5	3.2	0.1	29.4	0.2	34.1
		PSC	0.5	0.2	0.8	2.8	0.6	34.4	0.0	57.2	2.0	9.9	3.2	3.8	0.1	31.9	0.1	36.2
	3	None	0.3	0.3	0.6	4.3	0.5	38.9	0.0	64.0	1.7	11.9	2.7	4.9	0.1	36.1	0.1	39.6
		PS	0.0	0.6	0.5	8.6	0.3	46.8	0.0	74.7	1.1	17.0	2.0	8.1	0.0	46.3	0.0	47.8
		PSC	0.0	0.9	0.5	10.7	0.3	49.7	0.0	78.7	1.0	19.1	1.8	9.6	0.0	50.2	0.0	51.2
	4	None	0.0	0.9	0.4	11.2	0.3	50.3	0.0	79.5	1.0	18.9	1.8	9.6	0.0	49.8	0.0	50.9
		PS	0.0	2.9	0.2	19.1	0.2	60.4	0.0	88.4	0.6	27.1	1.3	15.5	0.0	62.5	0.0	61.4
		PSC	0.0	3.8	0.2	22.9	0.2	63.7	0.0	90.9	0.5	30.1	1.1	18.2	0.0	67.0	0.0	65.4

Values represent the percentage of each subgroup's nutrient intake lying below the subgroup-specific estimated average requirement (EAR) or above its upper limit (UL), respectively, at baseline (Level 0) and projected under different fortification and overage guidelines. Shading indicates the extent of projected intake deficiency or over-sufficiency (0%: green; 50%: yellow; 100%: red). See Methods and Table 2.1 for description of levels and references. Abbreviations: PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses). Iron and zinc losses in cooking flour products are negligible, therefore PSC overage for iron and zinc is not modeled.

Table S2.5: Prevalence of vitamins A and D intake deficiency (%<EAR) and over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter at baseline and projected under different flour and oil fortification and overage guidelines (rural areas)

		Nutrient:	Vitamin A								Vitamin D							
		Sex:	Females				Males				Females				Males			
		Season:	Summer		Winter		Summer		Winter		Summer		Winter		Summer		Winter	
Flour Fortification Level	Oil Fortification Level	Overage Guideline	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL	%< EAR	%> UL
0	0	None	40.0	0.6	71.3	0.4	49.1	2.8	41.5	5.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	1	None	38.1	0.7	68.5	0.2	46.8	5.5	36.4	6.8	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PS	37.3	0.7	68.1	0.1	45.8	5.4	35.0	6.8	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PSC	35.8	2.1	67.3	0.0	43.5	5.3	32.7	6.3	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	2	None	35.8	2.1	67.5	0.1	44.1	5.3	33.2	6.4	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PS	34.4	1.8	65.8	0.0	41.2	5.3	31.4	2.9	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PSC	30.5	1.3	61.2	0.0	35.6	5.1	26.9	2.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	3	None	34.3	1.7	65.6	0.0	40.7	5.3	31.0	2.8	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PS	31.2	1.4	61.5	0.0	35.9	5.1	27.1	2.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PSC	23.9	0.8	54.5	0.0	27.9	5.0	20.5	1.2	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	4	None	31.6	1.4	62.3	0.0	36.9	5.2	28.0	2.4	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PS	26.1	1.1	57.1	0.0	30.9	5.1	22.9	1.6	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PSC	18.2	0.6	44.7	0.0	21.1	5.1	15.0	0.7	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
1	0	None	25.2	1.8	53.6	1.2	33.7	4.3	18.5	2.4	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
		PS	18.2	1.6	47.2	1.3	27.2	4.5	10.6	1.1	100.0	0.0	100.0	0.0	99.8	0.0	100.0	0.0
		PSC	17.0	1.6	45.5	1.4	26.4	4.5	9.1	0.9	100.0	0.0	100.0	0.0	99.8	0.0	100.0	0.0
	1	None	22.6	1.5	50.0	1.0	30.9	4.6	13.9	1.9	100.0	0.0	100.0	0.0	99.9	0.0	100.0	0.0
		PS	15.3	1.3	41.8	1.1	23.1	4.9	6.7	0.8	100.0	0.0	100.0	0.0	99.7	0.0	100.0	0.0
		PSC	13.1	1.1	37.4	1.0	19.6	5.0	3.9	0.5	100.0	0.0	100.0	0.0	99.5	0.0	100.0	0.0
	2	None	20.9	1.3	47.1	0.9	27.6	4.6	10.9	1.4	100.0	0.0	100.0	0.0	99.8	0.0	100.0	0.0
		PS	12.7	1.0	36.9	0.9	18.6	5.0	3.9	0.5	100.0	0.0	100.0	0.0	99.4	0.0	100.0	0.0
		PSC	9.5	0.8	29.9	0.7	14.0	5.2	1.5	0.2	100.0	0.0	100.0	0.0	98.9	0.0	100.0	0.0
	3	None	18.6	1.2	44.1	0.7	24.3	4.6	8.5	1.0	100.0	0.0	100.0	0.0	99.7	0.0	100.0	0.0
		PS	10.4	0.9	32.1	0.7	15.1	5.1	2.1	0.3	100.0	0.0	100.0	0.0	99.0	0.0	100.0	0.0
		PSC	6.5	0.7	22.8	0.6	9.5	5.3	0.4	0.2	100.0	0.0	100.0	0.0	97.5	0.0	100.0	0.0
	4	None	16.7	1.1	40.9	0.6	21.0	4.7	6.3	0.8	100.0	0.0	100.0	0.0	99.6	0.0	100.0	0.0
		PS	8.1	0.7	27.2	0.6	11.7	5.2	1.0	0.2	100.0	0.0	100.0	0.0	98.2	0.0	100.0	0.0
		PSC	4.3	0.4	15.8	0.5	6.5	5.5	0.1	0.0	100.0	0.0	99.9	0.0	95.1	0.0	99.5	0.0
2	0	None	22.1	1.8	50.7	1.2	30.9	4.4	14.1	1.7	100.0	0.0	100.0	0.0	98.6	0.0	100.0	0.0
		PS	14.3	1.5	42.6	1.4	23.6	4.6	6.6	0.7	100.0	0.0	100.0	0.0	96.5	0.0	100.0	0.0
		PSC	13.3	1.5	40.8	1.4	22.5	4.6	5.2	0.6	100.0	0.0	100.0	0.0	96.5	0.0	100.0	0.0
	1	None	20.0	1.4	46.8	1.2	28.1	4.6	10.8	1.3	100.0	0.0	100.0	0.0	98.4	0.0	100.0	0.0
		PS	12.2	1.2	36.8	1.2	19.2	4.9	3.8	0.5	100.0	0.0	100.0	0.0	94.9	0.0	100.0	0.0
		PSC	10.1	0.9	32.6	1.2	16.4	5.2	1.9	0.3	100.0	0.0	100.0	0.0	93.8	0.0	100.0	0.0
	2	None	17.6	1.3	43.5	1.0	24.7	4.8	8.1	1.0	100.0	0.0	100.0	0.0	97.8	0.0	100.0	0.0
		PS	9.9	0.9	32.1	1.0	15.7	5.2	1.9	0.3	100.0	0.0	100.0	0.0	92.9	0.0	99.8	0.0
		PSC	7.0	0.8	24.9	0.8	11.2	5.3	0.6	0.1	100.0	0.0	99.9	0.0	89.7	0.0	99.1	0.0
	3	None	16.1	1.1	40.3	0.8	21.8	4.8	5.9	0.7	100.0	0.0	100.0	0.0	96.9	0.0	100.0	0.0
		PS	7.8	0.8	27.3	0.8	12.4	5.3	0.9	0.2	100.0	0.0	99.9	0.0	90.0	0.0	99.1	0.0
		PSC	4.9	0.6	19.1	0.7	7.6	5.6	0.1	0.0	100.0	0.0	99.6	0.0	84.6	0.0	95.6	0.0
	4	None	13.6	1.0	37.0	0.7	18.4	4.9	3.9	0.5	100.0	0.0	100.0	0.0	95.9	0.0	100.0	0.0
		PS	6.3	0.7	23.2	0.7	9.6	5.4	0.4	0.1	100.0	0.0	99.7	0.0	86.9	0.0	97.7	0.0
		PSC	3.2	0.3	13.6	0.6	5.1	5.8	0.0	0.0	100.0	0.0	98.5	0.0	78.5	0.0	88.8	0.0

Table S2.5 (continued)

		Nutrient:	Vitamin A								Vitamin D							
		Sex:	Females				Males				Females				Males			
		Season:	Summer		Winter		Summer		Winter		Summer		Winter		Summer		Winter	
Flour Fortification Level	**Oil Fortification Level**	**Overage Guideline**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**	**%< EAR**	**%> UL**
3	0	None	19.0	1.6	47.4	1.3	27.9	4.5	10.8	1.2	100.0	0.0	100.0	0.0	93.6	0.0	100.0	0.0
		PS	11.1	1.3	37.9	1.5	20.1	4.7	3.4	0.4	100.0	0.0	99.6	0.0	83.1	0.0	96.5	0.0
		PSC	10.2	1.3	35.6	1.5	19.0	4.8	2.5	0.3	100.0	0.0	99.6	0.0	83.1	0.0	96.5	0.0
	1	None	17.2	1.3	43.6	1.2	25.2	4.7	7.9	0.9	100.0	0.0	100.0	0.0	91.9	0.0	99.7	0.0
		PS	9.4	1.0	32.3	1.3	16.0	5.1	1.9	0.3	100.0	0.0	99.1	0.0	79.2	0.0	92.7	0.0
		PSC	7.4	0.9	27.9	1.2	13.7	5.4	0.8	0.2	100.0	0.0	98.7	0.0	77.1	0.0	89.8	0.0
	2	None	15.0	1.2	39.9	1.0	21.5	4.9	5.6	0.7	100.0	0.0	99.9	0.0	90.0	0.0	99.2	0.0
		PS	7.5	0.8	27.6	1.1	13.2	5.4	0.8	0.1	100.0	0.0	98.4	0.0	75.2	0.0	87.3	0.0
		PSC	4.7	0.7	21.1	0.9	9.2	5.5	0.2	0.0	100.0	0.0	97.0	0.0	70.3	0.0	79.1	0.0
	3	None	13.8	1.1	36.8	0.9	18.8	5.0	3.8	0.5	100.0	0.0	99.8	0.0	88.1	0.0	98.0	0.0
		PS	5.5	0.7	22.9	0.9	10.1	5.5	0.3	0.0	100.0	0.0	97.1	0.0	70.7	0.0	79.7	0.0
		PSC	3.3	0.6	15.6	0.8	6.2	6.0	0.0	0.0	100.0	0.0	94.5	0.0	63.1	0.0	67.5	0.0
	4	None	11.6	0.9	33.2	0.7	16.2	5.1	2.4	0.3	100.0	0.0	99.6	0.0	85.4	0.0	96.3	0.0
		PS	4.5	0.6	19.0	0.8	7.7	5.7	0.1	0.0	100.0	0.0	95.7	0.0	66.0	0.0	72.6	0.0
		PSC	2.0	0.3	10.7	0.6	4.3	6.2	0.0	0.0	99.8	0.0	90.8	0.0	55.2	0.0	55.9	0.0
4	0	None	16.2	1.6	44.0	1.4	25.4	4.5	7.7	0.8	100.0	0.0	99.1	0.0	81.1	0.0	93.1	0.0
		PS	8.4	1.3	33.6	1.5	17.1	4.9	1.6	0.2	100.0	0.0	93.3	0.0	61.0	0.0	63.2	0.0
		PSC	7.6	0.3	31.1	1.5	15.9	5.0	1.0	0.2	100.0	0.0	93.3	0.0	61.0	0.0	63.2	0.0
	1	None	14.4	1.3	39.8	1.2	22.1	4.9	5.2	0.6	100.0	0.0	98.6	0.0	78.2	0.0	89.7	0.0
		PS	7.0	0.9	28.0	1.3	13.7	5.3	0.8	0.1	100.0	0.0	90.6	0.0	57.0	0.0	55.1	0.0
		PSC	5.1	0.7	23.3	1.2	11.3	5.5	0.2	0.0	100.0	0.0	89.2	0.0	54.6	0.0	51.0	0.0
	2	None	12.8	1.1	36.2	1.1	19.3	5.0	3.4	0.5	100.0	0.0	98.0	0.0	75.2	0.0	85.1	0.0
		PS	5.3	0.7	23.3	1.1	10.4	5.5	0.2	0.0	100.0	0.0	88.0	0.0	52.5	0.0	47.5	0.0
		PSC	3.4	0.6	17.8	1.0	7.5	5.9	0.0	0.0	99.8	0.0	84.8	0.0	47.9	0.0	40.3	0.0
	3	None	11.0	1.0	33.1	1.0	16.6	5.1	2.2	0.3	100.0	0.0	97.2	0.0	72.3	0.0	80.2	0.0
		PS	4.0	0.6	19.8	1.0	8.3	5.8	0.1	0.0	99.8	0.0	85.1	0.0	48.2	0.0	40.8	0.0
		PSC	2.2	0.5	12.4	0.9	5.0	6.2	0.0	0.0	99.1	0.0	79.0	0.0	41.3	0.0	31.1	0.0
	4	None	9.6	0.8	29.7	0.8	14.2	5.2	1.4	0.2	100.0	0.0	96.0	0.0	69.1	0.0	74.3	0.0
		PS	3.1	0.6	16.0	0.8	6.3	6.0	0.0	0.0	99.4	0.0	81.2	0.0	44.2	0.0	35.2	0.0
		PSC	1.3	0.3	8.4	0.8	3.4	6.6	0.0	0.0	97.7	0.0	73.6	0.0	35.1	0.0	24.0	0.0

Values represent the percentage of each rural subgroup's nutrient intake lying below the subgroup-specific estimated average requirement (EAR) or above its upper limit (UL), respectively, at baseline (Level 0) and projected under different fortification and overage guidelines. Shading indicates the extent of projected intake deficiency or over-sufficiency (0%: green; 50%: yellow; 100%: red). See Methods and Table 2.1 for description of levels and references. Abbreviations: PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses).

Table S2.6: Median intake of D (IU/day) among different subgroups of Mongolian adults in summer and winter under at baseline and projected under different flour and oil fortification and overage guidelines (rural areas)

	Sex:	Females						Males					
	Season:	**Summer**			**Winter**			**Summer**			**Winter**		
Flour Fortification Level	**Oil Fortification Level**	**No Overage**	**PS Overage**	**PSC Overage**	**No Overage**	**PS Overage**	**PSC Overage**	**No Overage**	**PS Overage**	**PSC Overage**	**No Overage**	**PS Overage**	**PSC Overage**
0	0	29.1	29.1	29.1	18.2	18.2	18.2	41.1	41.1	41.1	31.3	31.3	31.3
	1	34.5	36.6	40.8	27.4	30.9	36.8	54.1	59.9	70.0	44.3	49.4	58.1
	2	39.7	44.3	52.1	35.3	41.9	53.2	67.6	78.4	97.2	56.0	65.6	82.8
	3	45.1	51.6	63.0	43.0	52.3	69.5	80.1	95.8	122.9	67.2	81.4	107.1
	4	50.1	58.6	73.8	50.3	62.9	85.3	92.3	112.6	148.7	78.4	97.3	131.6
1	0	67.8	78.5	78.5	69.4	82.0	82.0	105.5	123.4	123.4	102.1	119.5	119.5
	1	72.8	85.8	89.8	76.9	92.7	98.2	117.4	140.0	148.7	113.3	135.3	143.9
	2	78.3	93.1	100.8	84.3	103.1	114.4	128.9	156.6	174.7	124.3	151.1	167.7
	3	83.4	100.2	111.8	91.7	113.6	130.3	140.9	173.4	200.1	135.6	166.6	191.9
	4	88.4	107.4	122.6	99.0	123.9	146.3	152.8	189.7	225.7	146.3	182.3	215.8
2	0	105.7	127.3	127.3	119.0	144.0	144.0	167.7	202.2	202.2	170.3	204.6	204.6
	1	110.7	134.4	138.2	126.5	154.6	160.3	178.8	218.4	228.0	181.3	220.3	228.8
	2	115.8	141.5	149.3	133.8	165.1	176.2	190.0	235.6	253.4	192.4	236.0	252.7
	3	120.9	148.7	160.0	141.1	175.4	192.0	201.7	252.2	278.2	203.1	251.4	276.5
	4	125.8	155.8	171.2	148.3	185.7	207.8	213.4	268.5	303.8	214.1	267.1	300.3
3	0	143.7	175.9	175.9	168.4	206.1	206.1	229.0	281.8	281.8	237.9	289.5	289.5
	1	148.6	183.0	186.8	175.9	216.5	222.1	240.5	298.0	305.8	248.9	305.0	313.5
	2	153.7	190.3	197.8	183.1	227.0	238.1	251.7	313.2	330.3	259.9	320.6	337.2
	3	158.6	197.2	208.7	190.4	237.3	253.8	262.6	329.3	355.1	270.9	336.1	362.9
	4	163.6	204.4	219.7	197.7	247.6	269.0	274.3	345.0	381.7	281.7	351.4	386.7
4	0	181.4	224.3	224.3	217.9	268.0	268.0	290.5	360.2	360.2	305.7	374.2	374.2
	1	186.5	231.6	235.4	225.2	278.3	284.0	301.8	374.7	383.1	316.5	389.8	398.0
	2	191.5	238.7	246.3	232.6	288.9	300.3	312.6	390.8	407.7	327.5	405.2	421.9
	3	196.5	245.7	257.3	239.9	299.5	300.3	323.4	406.6	433.4	338.3	420.5	447.7
	4	201.5	252.9	268.2	247.0	309.5	300.3	334.5	422.0	459.9	349.1	436.1	472.1
Female Optimum	0	318.3	400.0	400.0	323.2	400.0	400.0	504.1	635.0	635.0	452.0	557.9	557.9
Male Optimum	0	203.1	252.1	252.1	232.0	285.5	285.5	325.0	400.0	400.0	324.9	400.0	400.0

Values represent the median intake of vitamin D (IU/day) in each rural subgroup at baseline (Level 0) and projected under different fortification and overage guidelines. Shading indicates the magnitude of projected median intake (minimum (18.2 IU/day): red; median (190.0 IU/day): yellow; estimated average requirement (400.0 IU/day): green). See Methods and Table 2.1 for description of Levels 0-4, overage guidelines, and references, and methods and Table 2.9 for description and specifications of male and female optimal levels. Abbreviations: IU (international unit; 40 IU = 1 µg), PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses).

Table S2.7: Estimated optimal flour fortification levels for thiamin, riboflavin, and folate, and their projected effects on the prevalence of intake deficiency (%<EAR) among different subgroups of Mongolian adults in summer and winter under different overage guidelines

			Area and Season:	**Rural Summer**			**Rural Winter**		
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Optimum**	**Overage Guideline**	**Optimal Level (per 100g of vehicle)**	**%<EAR, Females**	**%<EAR, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%<EAR, Males**
Thiamine	0.4 mg	Female Optimum	None	0.3 mg	18.3	10.9	0.4 mg	18.7	1.5
			PS		7.8	6.6		7.9	0.3
			PSC		4.8	5.2		4.8	0.1
		Male Optimum	None	0.3 mg	17.2	10.5	0.2 mg	51.4	14.1
			PS		7.0	6.2		38.3	6.9
			PSC		4.3	4.9		31.8	4.4
Riboflavin	0.4 mg	Female Optimum	None	0.0 mg	3.4	5.3	0.1 mg	6.1	0.2
			PS		3.4	5.3		5.0	0.1
			PSC		3.4	5.3		4.7	0.0
		Male Optimum	None	0.0 mg	3.1	5.0	0.0 mg	10.9	0.6
			PS		3.1	4.9		10.9	0.6
			PSC		3.1	4.9		10.9	0.6
Folate	100 µg, 130 µg, 150 µg	Female Optimum	None	187.0 µg	73.2	25.2	210.7 µg	36.4	3.6
			PS		25.4	10.2		15.6	0.6
			PSC		4.9	4.7		5.0	0.0
		Male Optimum	None	183.2 µg	75.3	26.3	104.1 µg	82.7	42.3
			PS		28.0	10.8		65.0	18.9
			PSC		6.1	5.0		42.1	5.0
Vitamin B12	0.80 µg, 1.00 µg	Female Optimum	None	0.0 µg	0.0	0.0	0.0 µg	0.0	0.0
			PS		0.0	0.0		0.0	0.0
		Male Optimum	None	0.0 µg	0.0	0.0	0.0 µg	0.0	0.0
			PS		0.0	0.0		0.0	0.0

Table S2.7 (continued)

			Area and Season:	Rural Summer			Rural Winter		
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Optimum**	**Overage Guideline**	**Optimal Level (per 100g of vehicle)**	**%<EAR, Females**	**%<EAR, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%<EAR, Males**
Thiamine	0.4 mg	Female Optimum	None	0.4 mg	14.3	5.9	0.7 mg	14.9	2.2
			PS		6.9	1.4		7.0	0.3
			PSC		5.0	0.7		4.9	0.1
		Male Optimum	None	0.3 mg	25.9	15.8	0.3 mg	36.8	18.3
			PS		16.4	7.5		25.1	7.6
			PSC		13.3	4.9		20.4	4.7
Riboflavin	0.4 mg	Female Optimum	None	0.1 mg	5.5	6.9	0.2 mg	6.1	1.4
			PS		5.0	5.9		5.1	0.9
			PSC		4.8	5.6		4.8	0.7
		Male Optimum	None	0.1 mg	5.1	6.2	0.0 mg	11.4	4.8
			PS		4.4	5.0		11.4	4.8
			PSC		4.2	4.7		11.4	4.8
Folate	100 µg, 130 µg, 150 µg	Female Optimum	None	260.7 µg	28.0	3.6	336.7 µg	26.1	1.0
			PS		10.9	0.2		10.8	0.1
			PSC		5.0	0.0		5.0	0.0
		Male Optimum	None	129.2 µg	69.9	44.6	133.6 µg	77.5	42.9
			PS		46.6	15.7		59.6	15.7
			PSC		31.7	5.0		42.9	5.0
Vitamin B12	0.80 µg, 1.00 µg	Female Optimum	None	0.0 µg	0.5	0.0	0.0 µg	0.0	0.0
			PS		0.5	0.0		0.0	0.0
		Male Optimum	None	0.0 µg	0.5	0.0	0.0 µg	0.0	0.0
			PS		0.5	0.0		0.0	0.0

"Optimal Level" represents the estimated concentration of nutrient needed to achieve a post-fortification intake deficiency prevalence of 5% in a specific urban or rural area, season, and sex under maximum overage guidelines for processing, storage, and cooking (if the baseline prevalence is equal to or less than 5%, the optimal level is set to 0). For comparison, published levels are reproduced from Table 2.1. The projected effect of each area-, season-, and sex-specific optimal level on the prevalence of deficiency (%<EAR) is modeled for both sexes in the same area and season under different overage guidelines. Shading indicates the extent of projected deficiency (0%: green; 50%: yellow; 100%: red). Abbreviations: PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses). Vitamin B12 losses in cooking flour products are negligible, therefore PSC overage for vitamin B12 is not modeled.

Table S2.8: Estimated optimal flour fortification levels for zinc, vitamin A, vitamin D, and niacin, and their projected effects on the prevalence of intake deficiency (%<EAR) and over-sufficiency (%>UL) among different subgroups of Mongolian adults in summer and winter under different overage guidelines

			Area and Season:	**Rural Summer**					**Rural Winter**				
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Guideline**	**Overage Guideline**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**
Iron	2.0 mg, 3.0 mg	Female Optimum	None	2.6 mg	5.4	0.0	0.0	2.3	1.3 mg	5.2	0.0	0.0	0.0
			PS		5.1	0.0	0.0	2.4		5.0	0.0	0.0	0.0
		Male Optimum	None	0.0 mg	18.7	0.0	0.5	0.0	0.0 mg	10.6	0.0	0.0	0.0
			PS		18.7	0.0	0.5	0.0		10.6	0.0	0.0	0.0
Zinc	3.0 mg, 4.0 mg	Female Optimum	None	0.0 mg	1.4	0.0	0.8	0.2	0.0 mg	1.9	0.0	0.5	2.5
			PS		1.4	0.0	0.8	0.2		1.9	0.0	0.5	2.5
		Male Optimum	None	0.0 mg	1.4	0.0	0.8	0.2	0.0 mg	1.9	0.0	0.5	2.5
			PS		1.4	0.0	0.8	0.2		1.9	0.0	0.5	2.5
Vitamin A	100 µg, 150 µg	Female Optimum	None	151.8 µg	13.3	1.5	22.4	4.6	267.0 µg	16.5	1.8	0.0	0.0
			PS		5.9	0.3	14.3	5.1		6.2	2.0	0.0	0.0
			PSC		5.0	0.3	12.7	5.2		5.0	2.1	0.0	0.0
		Male Optimum	None	210.5 µg	5.8	0.3	13.8	5.1	105.5 µg	50.6	1.2	14.0	1.7
			PS		1.3	0.3	5.9	5.8		42.7	1.4	6.6	0.7
			PSC		1.0	0.3	5.0	6.0		40.6	1.4	5.0	0.6
Vitamin D	55 IU	Female Optimum	None	209.4 IU	96.3	0.0	27.0	0.0	168.7 IU	77.6	0.0	28.4	0.0
			PS		50.0	0.0	11.6	0.0		50.0	0.0	7.6	0.0
			PSC		50.0	0.0	11.6	0.0		50.0	0.0	7.6	0.0
		Male Optimum	None	125.7 IU	100.0	0.0	71.4	0.0	117.8 IU	98.3	0.0	86.7	0.0
			PS		100.0	0.0	50.0	0.0		89.1	0.0	50.0	0.0
			PSC		100.0	0.0	50.0	0.0		89.1	0.0	50.0	0.0
Niacin	3.0 mg	Female Optimum	None	0.9 mg	6.2	0.0	2.0	11.1	1.1 mg	6.1	0.3	0.1	24.1
			PS		5.3	0.0	1.9	12.5		5.2	0.4	0.1	26.9
			PSC		5.0	0.0	1.8	12.9		5.0	0.5	0.0	28.0
		Male Optimum	None	0.0 mg	11.6	0.0	3.4	6.1	0.0 mg	13.0	0.1	0.5	15.4
			PS		11.6	0.0	3.4	6.1		13.0	0.1	0.5	15.4
			PSC		11.6	0.0	3.4	6.1		13.0	0.1	0.5	15.4

Table S2.8 (continued)

Area and Season:				Urban Summer					Urban Winter				
Nutrient	**Published Levels (per 100g of flour)**	**Modeled Guideline**	**Overage Guideline**	**Optimal Level (per 100g of vehicle)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**	**Optimal Level (per 100g of flour)**	**%<EAR, Females**	**%>UL, Females**	**%<EAR, Males**	**%>UL, Males**
Iron	2.0 mg, 3.0 mg	Female Optimum	None	3.1 mg	5.4	0.3	0.0	0.3	4.6 mg	5.3	1.0	0.0	6.9
			PS		5.0	0.4	0.0	0.4		5.0	1.2	0.0	7.8
		Male Optimum	None	0.0 mg	16.8	0.0	0.2	0.0	0.0 mg	22.2	0.0	0.0	0.3
			PS		16.8	0.0	0.2	0.0		22.2	0.0	0.0	0.3
Zinc	3.0 mg, 4.0 mg	Female Optimum	None	0.0 mg	2.1	0.1	0.5	0.2	0.0 mg	0.3	0.0	0.8	1.0
			PS		2.1	0.1	0.5	0.2		0.3	0.0	0.8	1.0
		Male Optimum	None	0.0 mg	2.1	0.1	0.5	0.2	0.0 mg	0.3	0.0	0.8	1.0
			PS		2.1	0.1	0.5	0.2		0.3	0.0	0.8	1.0
Vitamin A	100 µg, 150 µg	Female Optimum	None	220.6 µg	12.5	0.8	17.9	4.4	395.3 µg	11.5	0.5	0.3	7.6
			PS		5.6	1.2	7.9	5.2		5.6	1.0	0.0	10.0
			PSC		5.0	1.2	6.8	5.3		5.0	1.1	0.0	10.5
		Male Optimum	None	240.5 µg	10.5	0.8	14.8	4.6	176.0 µg	36.7	0.2	11.7	9.7
			PS		4.4	1.3	5.8	5.5		26.0	0.3	6.1	9.1
			PSC		3.8	1.3	5.0	5.7		24.6	0.3	5.0	9.1
Vitamin D	55 IU	Female Optimum	None	178.8 IU	73.4	0.0	38.8	0.0	207.1 IU	72.5	0.0	26.4	0.0
			PS		50.0	0.0	9.7	0.0		50.0	0.0	8.0	0.0
			PSC		50.0	0.0	9.7	0.0		50.0	0.0	8.0	0.0
		Male Optimum	None	129.4 IU	92.7	0.0	85.3	0.0	135.0 IU	95.1	0.0	22.6	0.0
			PS		78.6	0.0	50.0	0.0		85.6	0.0	50.0	0.0
			PSC		78.6	0.0	50.0	0.0		85.6	0.0	50.0	0.0
Niacin	3.0 mg	Female Optimum	None	1.3 mg	6.1	2.7	0.9	12.6	2.0 mg	6.4	0.9	0.5	22.6
			PS		5.3	3.2	0.6	13.9		5.3	1.4	0.4	25.6
			PSC		5.0	3.4	0.5	14.6		5.0	1.6	0.3	26.9
		Male Optimum	None	0.0 mg	10.9	1.2	2.2	6.8	0.0 mg	13.4	0.2	2.0	12.7
			PS		10.9	1.2	2.2	6.8		13.4	0.2	2.0	12.7
			PSC		10.9	1.2	2.2	6.8		13.4	0.2	2.0	12.7

"Optimal Level" represents the estimated concentration of nutrient needed to achieve a post-fortification intake deficiency prevalence of 5% (50% in the case of vitamin D) in a specific urban or rural area, season, and sex under maximum overage guidelines for processing, storage, and cooking (if the baseline prevalence is equal to or less than this percentage, the optimal level is set to 0). For comparison, published are reproduced from Table 2.1. The projected effect of each area-, season-, and sex-specific optimal level on the prevalence of intake deficiency (%<EAR) and over-sufficiency (%>UL) is modeled for both sexes in the same area and season under different overage guidelines. Shading indicates the extent of projected deficiency or over-sufficiency (0%: green; 50%: yellow; 100%: red). Abbreviations: IU (international unit; 40 IU = 1 µg), PS (overage for processing and storage losses), PSC (overage for processing, storage, and cooking losses). Iron and zinc losses in cooking flour products are negligible, therefore PSC overage for iron and zinc is not modeled.

III. Comparison of methods for estimating dietary food and nutrient intakes and intake densities from household consumption and expenditure data in Mongolia

Abstract

Background: Household consumption and expenditure surveys are frequently conducted around the world and usually include data on household food consumption. The applicability of these data to nutrition research is limited partly by their collection at the household- rather than individual- (dietary-) level.

Methods: Using household food consumption and individual dietary intake data from Mongolia, this study evaluated four approaches for estimating diet from household surveys: (1) direct inference from per-capita household consumption; disaggregation of household consumption using (2) a statistical method based on a regression approach and (3) the "adult male equivalent" (AME) method based on relative caloric requirements; and (4) direct prediction of dietary intake given the availability of different household- and individual-level variables with which to build a model.

Results: Per-capita household consumption overestimated dietary energy in single- and multi-person households by factors of 2.63 and 1.89, respectively (correlation: 0.09 and 0.29). Performance of disaggregation methods was variable in terms of mean bias (range: +302 to +1088 kcal/day and -918 to +163 kcal/day for AME and statistical methods, respectively, across two household surveys analyzed), while the statistical method exhibited less bias than the AME method in estimating intake densities (per 100 kcal) of most dietary components in both surveys. Increasingly complex prediction models explained 54% to 72% of in-sample variation in dietary energy (mean absolute error: 229 to 178 kcal/day), with consistent marginal benefits to model fit incurred by additional inclusion of basic dietary measurements and eating behaviors.

Interpretation: In Mongolia and elsewhere, differences in how household and dietary measurements are recorded make their comparison challenging. Validity of disaggregation methods depends on household survey characteristics and the dietary components considered. Relatively precise prediction models of dietary intake can be achieved by integrating basic dietary assessment into household surveys, which should be considered for nutrition surveillance in developing countries.

Introduction

Low coverage, frequency, and quality of dietary data from industrializing populations are significant obstacles in understanding diet-disease relationships and designing effective nutrition policies and programs around the world (Neufeld 2013). While developed countries often benefit from large, periodic surveys which collect 24-hour recall, diet record, or food-frequency data (Harris 2013), dietary surveys in developing countries typically employ less rigorous methodologies owing to the resources required for hiring dieticians or training community health workers, collecting dietary measurements from hundreds or thousands of people, and compiling local food composition data of adequate expansiveness (Ferro-Luzzi 2003, Coates 2017a). To save money, nutrition surveys in developing countries sometimes collect data at the household- rather than the individual- (dietary-) level, which usually involves asking questions about household food security or dietary diversity (Swindale 2005, Kennedy 2011). Such data are suited to address key nutritional questions, but they do not allow complete enumeration of household food or nutrient consumption, and the range of interventions which these data can inform are limited accordingly.

In contrast with household food security assessments, a more detailed class of household survey - the household consumption and expenditure (HCE) survey, frequently administered by national statistical offices - had been collected at least 700 times from 116 countries as of 2012 (Fiedler 2013a). Along with many useful covariates, HCE data often contain information on recent household food consumption (collected using a household diary or recall instrument), and are relatively inexpensive to collect periodically (Fiedler 2013b). While HCE data are more applicable to designing and evaluating nutrition interventions than food balance sheets (Gibson 2012), their limitations have been characterized extensively, as have the validity of household food consumption estimates (Smith 2014). A fundamental limitation of HCE data for nutrition research is that, with the exception of single-person households, they do not allow direct estimation of dietary intake by individuals but of per-capita household consumption among different household strata (e.g. defined by region, season, or socio-economic status), which is useful for informing certain interventions but not others (Coates 2012). Disaggregation of household food consumption to estimate individuals' dietary intake (i.e. "individualization") requires often tenuous assumptions, and is frequently limited to screening for dietary intake deficiencies or estimating dietary intake of specific fortification vehicles rather than broader nutritional surveillance or epidemiology (Sibrian 2008, Fiedler 2009). The former are important objectives in and of themselves, however.

One approach to disaggregating household consumption data, called the adult male equivalent (AME) or adult equivalent unit (AEU) method, is commonly used for estimating individuals' dietary intake in the absence of dietary measurements (Dary 2010, Weisell 2012). The AME method divides consumption of household foods or nutrients (collected as part of an HCE survey) in a manner proportional to the predicted nutrient requirements of household members (usually energy requirements). For the AME method to be accurate, a primary assumption that must be met is that household distribution of consumed foods and nutrients is equitable with respect to household members' caloric requirements. There is evidence that this assumption holds for certain demographics within certain national populations, but not others (Berti 2012). An alternative disaggregation method using regression was proposed by Chesher in 1997, based on work by Engle and colleagues (Engle 1986, Chesher 1997), and has arisen in the literature sporadically since its conception. This statistical method involves an indirect inference of individuals’ dietary intake through prediction of total household food consumption. Attempts have not been made to validate this method against dietary measurements or to compare its performance with the AME method.

In this study, we analyzed a combination of household food consumption and individual dietary measurements from Mongolia to assess the comparative usefulness of four approaches for applying household survey data to estimate dietary food and nutrient intake and intake density (i.e. intake per 100 kcal) in that country. Our four aims were the following (these four aims are referred to by number throughout this paper):

(1) To compare (a) per-capita estimates of household food and nutrient consumption obtained from household-level measurements with (b) per-capita dietary measurements obtained from individuals in the same households;
(2) To compare (a) estimates of individuals' food and nutrient intake obtained by applying the AME disaggregation method to household consumption measurements with (b) direct measurements of dietary intake obtained from the same individuals;
(3) To compare (a) estimates of individuals' food and nutrient intake obtained by applying the statistical disaggregation method to household consumption measurements with (b) direct measurements of dietary intake obtained from the same individuals;
(4) To evaluate the ability of household survey data to predict individuals' dietary nutrient intake given the availability of (i) direct dietary measurements and (ii) a broad set of household- and individual level characteristics obtained from the same individuals.

Methods

Sources of household food consumption data

Data from two nationally-representative household surveys in Mongolia were analyzed in this study: the 2013 Food Consumption Survey (FCS-HH) (MIN 2016) conducted by the Mongolian University of Science and Technology (n = 1,017 households comprising 4,087 individuals), and pooled 2012 and 2014 independently-sampled survey waves of the Household Socio-Economic Survey (HSES-HH) conducted by the National Statistics Office (n = 28,985 households comprising 106,760 individuals) (NSO 2014). The FCS-HH and HSES-HH collected data on household consumption of 116 and 118 different foods, respectively, from three sources (foods produced, purchased, and received as gifts, only the sum of which was analyzed in the current study) over a recent reference period, using a recall instrument in the case of the FCS-HH and a daily diary in the HSES-HH. The reference period was defined as the past week or month (whichever was more convenient for the household's enumerator to recall for each food) in the case of the FCS-HH, the past week in the case of rural households in the HSES-HH, and the past 10, 10 to 20, and 20 to 30 days in the case of urban households in the HSES-HH. (Throughout this paper, "urban" is used to refer to the capital municipality of Ulaanbaatar and province (*aimag*) and county (*soum*) centers, while "rural" refers to more remote settlements and the countryside). Although pooling data from all three HSES-HH reference periods would allow more precise long-term estimates of household consumption, more proximal periods (the last 20 days of record collection) have been observed to be more prone to underreporting in prior survey waves (Troubat 2017) (as we also found in exploratory analyses of the 2012-2014 waves), in part due to fatigue incurred by maintaining a diary of household consumption for an entire month. Considering this, this study analyzed HSES-HH household food consumption data from the more distal first 10 days only. HSES-HH waves were conducted year-round while the FCS-HH was conducted from May to August; for comparability with the FCS-HH, analysis of HSES-HH data were thus restricted to 9,849 households comprising 35,920 individuals from which data were collected between those months.

Sources of dietary intake data

In addition to the aforementioned sources of household data, the current study also analyzed 24-hour dietary recall (24HR) data collected from a subset of 1,369 randomly-sampled individuals aged 15 years or older participating in the FCS (this nested dataset is referred to as the FCS-24). Dietary data were not collected from participants in the HSES. FCS-24 participants were guided through the 24HR according to a standardized instrument and protocol developed by dieticians at the University of Science and Technology, based on a protocol and multiple-pass method used in the Korea National Health and Nutrition Examination Survey, which incorporated a booklet of photographs containing suggested portion sizes.

These recall data describe individuals' dietary intakes of 160 distinct food items composed of 136 distinct ingredients. Nutritional analysis of the FCS-HH, nested FCS-24, and HSES-HH also drew upon ancillary data on food composition, cooking yields, and components of variance in dietary nutrient intake collected and analyzed from 2012 to 2016 as part of a separate nationwide dietary assessment, in which paired summer and winter 3-day weighed diet records were collected 320 healthy Mongolian men and women aged 22-55 living in urban and rural areas of 7 national provinces and Ulaanbaatar (Bromage 2017).

Participants of the FCS-HH and nested FCS-24, HSES-HH, and nationwide diet records surveys provided written informed consent prior to enrollment. Collection of these surveys' data and their analysis in the current study was permitted by the ethics boards of the National Statistical Office of Mongolia, Mongolian University of Science and Technology, and Harvard T.H. Chan School of Public Health, respectively.

Preparation of data for analysis

Foods across the FCS-HH, nested FCS-24, and HSES-HH were condensed into 11 food groups, ages were condensed into 10 age groups, and variables were created to describe individuals' total daily predicted caloric requirement, each household's fractions of total caloric requirements contributed by permanent and impermanent members, and household family composition category (Appendix A, Table S3.1). Survey weights were derived for the FCS-HH, nested FCS-24, and HSES-HH using the national census (Appendix B). Household food consumption in the FCS-HH and HSES-HH was converted to g/day and adjusted for refuse, spoilage, waste, and eating out (Appendix C). Individuals' daily dietary nutrient intake in the FCS-24, and households' total daily nutrient consumption in the FCS-HH and HSES-HH were calculated using a purpose built food composition table incorporating locally-analyzed food samples and locally-collected recipes and yield factors; dietary intake and household consumption of food groups and nutrients were also expressed in "energy-adjusted" terms (per 100 kcal of intake or consumption, respectively) to produce "intake densities" and "consumption densities", respectively (Appendix D). Individuals' dietary nutrient intakes in the FCS-24 were adjusted for within-person variance using variance components estimated for the national population (Appendix E, Table S3.2).

Exclusion criteria and descriptive statistics

Four hundred and thirteen households in the HSES-HH were excluded from further analyses for containing no permanent household members. Five and 16 households in the FCS-HH and HSES-HH, respectively, for which the ratio of calories in total household food consumption to the total predicted energy expenditure of household members lay 3 standard deviations beyond the median were further excluded, following a comparable approach for individuals in the literature (e.g. Mulligan 2014). One individual with no observed dietary intake was excluded from analysis of the FCS-24HR, and 4 were further excluded for having extreme ratios of daily total energy intake (TEI) to total energy expenditure (TEE) (> or <3SD) after adjustment for within-person variance. While such extreme values are not necessarily implausible for individuals given only one day of observed intake, their plausibility was considered less likely after adjustment for within-person variance. Such extreme values were generally considered less plausible for households in the FCS-HH and HSES-HH given the length of the reference periods considered in the household surveys.

After applying exclusion criteria, 109 FCS-HH households were available in which 24HR data had been collected from all household members, allowing direct comparison between per-capita household consumption and per-capita dietary measurements from the same households (Aim 1); 9,424 and 1,012 households were available in the HSES-HH and FCS-HH, respectively, for disaggregation of household food group and nutrient consumption to estimate dietary intakes of individuals (Aims 2 and 3); and FCS-24 dietary data were available from 1,356 individuals for comparison with disaggregated household consumption estimates (Aims 2 and 3) and prediction of individuals' dietary nutrient intakes (Aim 4). A summary of the sources of data analyzed in each of the four Aims is provided in Figure 3.1. Demographic and socioeconomic characteristics of households and constituent household members in the FCS-HH and

HSES-HH were tabulated after applying exclusion criteria (Table 3.1), as were the proportions of individuals in the FCS24 and households in the FCS-HH and HSES-HH observed to consume any of each food group or nutrient during each survey's reference period and the correlations between food groups and selected nutrients within both the FCS-HH and FCS-24 datasets.

Figure 3.1: Sources of data

Initial sources of data (prior to applying exclusion criteria)

2013 Food Consumption Survey (FCS-HH): household food consumption recall collected from 1017 households comprising 4087 individuals

24-hour recall (FCS-24): dietary assessment collected from a subset of 1369 individuals across 768 FCS-HH households

A subset of FCS-HH households in which all household members participated in the FCS-24 (n = 109 households and 196 individuals).

Summer 2012 and 2014 waves of the Household Socio-Economic Survey (HSES-HH): household food consumption diary collected from 9849 households comprising 35920 individuals

Source of data for Aim 1: Direct comparison between per-capita dietary measurements and per capita household consumption measurements

A subset of FCS-HH households in which all household members participated in the FCS-24 (n = 109 households and 196 individuals).

Sources of data for Aims 2 and 3: Statistical and AME disaggregation of household food and nutrient consumption

2013 Food Consumption Survey (FCS-HH): household food consumption recall collected from 1012 households comprising 4070 individuals

24-hour recall (FCS-24): dietary assessment collected from a subset of 1356 individuals across 765 FCS-HH households

Summer 2012 and 2014 waves of the Household Socio-Economic Survey (HSES-HH): household food consumption diary collected from 9424 households comprising 34946 individuals

Source of data for Aim 4: Direct prediction of nutrient intake by individuals

24-hour recall (FCS-24): dietary assessment collected from a subset of 1356 individuals across 765 FCS-HH households

See Methods for description of exclusion criteria and information regarding ancillary diet records and national census data used in preparing and analyzing the FCS-HH, nested FCS-24, and HSES-HH.

Table 3.1: Characteristics of households and individuals in the FCS-HH and HSES-HH

	Household Survey:	**FCS-HH**	**HSES-HH**
Household Characteristics	Households (n)	1012	9424
	Location, n (%)		
	Ulaanbaatar	472 (46.6)	2332 (24.7)
	Provincial/county center	168 (16.6)	4937 (52.4)
	Rural	372 (36.8)	2155 (23.3)
	Household size, mean (SD)	4.0 ± 1.7	3.3 ± 1.6
	Family composition n (%)		
	1 man	40 (4.0)	574 (6.1)
	1 woman	34 (3.4)	662 (7.0)
	2 or more adults	326 (32.2)	2922 (31.0)
	Adult(s) and children	612 (60.5)	5235 (55.5)
	Children only	0 (0.0)	31 (0.3)
	Maximum education (years), n (%)		
	0 to 4	32 (3.2)	694 (7.4)
	6 to 10	593 (58.6)	4719 (50.1)
	14+	387 (38.2)	4011 (42.6)
	% TEE from impermanent members, mean (SD)	1.81 ± 3.28	2.5 ± 8.2
	% food spending outside home, mean (SD)	12.1 ± 12.3	9.1 ± 24.6
	Household TEI/TEE, mean (SD)	1.35 ± 0.65	1.09 ± 0.79
Individual Characteristics	Individuals (n)	4070	34946
	Age (years), mean (SD)	28.7 ± 19.6	28.4 ± 19.1
	Sex, n (%)		
	Female	2140 (52.6)	17873 (51.1)
	Male	1930 (47.4)	17073 (48.9)
	Married or living with partner, n (%)	1648 (40.5)	17667 (50.6)
	TEI/TEE, mean (SD)	0.77 ± 0.14	-

Values indicate n, n (%), or mean ± SD. Statistics are derived after restricting HSES-HH data to those collected in May, June, July, or August, and after applying exclusion criteria. % household total energy expenditure (TEE) from guests and visitors and % of food spending are expressed as "during the reference period" of each survey. Four years of education corresponds to completion of primary school; 6: currently in secondary school; 10: completed high school or vocational training; 14: completed bachelor degree. Abbreviations: FCS-HH (2013 Food Consumption Survey), HSES-HH (2012/2014 Household Socio-Economic Survey), TEI (total energy intake).

Aim 1: Direct comparison between per-capita household consumption and per-capita dietary measurements from the same households

An initial assessment of the comparability of individual dietary intake and household consumption measurements was made by considering the subset of109 FCS-HH households whose members were fully-enumerated by the nested FCS-24 (i.e. FCS-HH households for which 24HR measurements were collected for all individual household members, in addition to total household food consumption as measured using the household recall instrument). For each of these 109 FCS-HH households, estimates of daily per-capita food group and nutrient consumption and consumption densities (consumption per 100 kcal) were derived from household food consumption measurements, as were per-capita dietary food group and nutrient intakes and intake densities derived from the sum of 24HR measurements collected from all household members. Among both single-person and multi-person households, mean per-capita household consumption and consumption density of each food group and nutrient was calculated from per-capita household consumption estimates, mean per-capita dietary intake and intake density was calculated from per-capita dietary intake estimates, and mean difference, mean ratio, Pearson correlation coefficient, and Spearman rank correlation coefficient were calculated between paired per-capita household-derived and dietary-derived measurements from the same households. Calculation of mean ratios excluded a single two-person household with implausibly low per-capita household energy consumption (3 kcal/day).

Aim 2: Statistical disaggregation of household food and nutrient consumption

Two disaggregation methods were applied to the FCS-HH and HSES-HH in an attempt to estimate dietary food group and nutrient intake by household members. First, a “statistical” disaggregation method was applied using generalized linear models (R v3.4 ‘glm’ package) with a Tweedie response distribution and identity link function (Jørgensen 1997). This allowed for a set of models which could flexibly accommodate both zero-inflated and right-skewed response data (issues in analysis of food groups, and both food groups and nutrients, respectively) and provided easily interpretable parameter estimates on the response scale. Total daily household consumption of each food group and nutrient was regressed in a survey-weighted model on 25 household variables, including a set of 20 integer variables collectively describing the number of household members of each age-sex group in each household, the fraction of household daily energy expenditure contributed by the person-time of impermanent members, family composition category, locality (urban, peri-urban/suburban, and rural), the fraction of household food spending on food eaten outside home, and the maximum number of years of education obtained by any household member (given Mongolia's sizeable population of nomadic pastoralists, education is considered a more useful measure of socio-economic status than income (Dorjdagva 2015); adjustment for family composition and consumption by impermanent members generally follows methods described by Chesher (Chesher 1997)).

Models were fit for each of 21 possible values of the Tweedie index parameter *p* (ranging from 1 to 3 in increments of 0.1) to select the parameter value which produced the smallest ratio of residual to null deviance. Models were weighted using the survey weights previously described. The parameter estimates associated with each of the 10 age groups within each sex were extracted along with their respective 95% confidence limits to derive sex-specific age-intake relationships for each food group and nutrient, each of which was smoothed across the age groups using regression splines and a subjective smoothing parameter selected based on visual inspection ("gam" package) (Wood 2006). After smoothing, negative parameter estimates and confidence limits were adjusted to 0 for interpretability. Goodness of fit for each model was recorded in terms of the proportion of deviance explained (1-residual deviance/null deviance), associated Chi-square test p-value, and mean absolute error. For each age- and sex-group, disaggregated household consumption density estimates (estimated consumption per 100 kcal) were obtained by dividing the group's disaggregated estimate of food group or nutrient consumption by its disaggregated estimate of energy consumption and multiplying by 100. A similar approach to obtaining nutrient ratios by "manipulating estimates of underlying nutrient intakes" from a pair of statistical disaggregation models follows that first used by Chesher (Chesher 1997, 1998).

Aim 3: AME disaggregation of household food and nutrient consumption

To obtain results more comparable with the statistical method's, application of the adult male equivalent (AME) method was preceded by adjustment of daily household food group and nutrient consumption in the FCS-HH and HSES-HH for the variables family composition, household locality, fraction of outside food spending, maximum number of years of education attained, and fraction of household energy consumption attributed to the person time of impermanent members (variables also adjusted for in analysis using the statistical method). Adjustment proceeded using the residual method (Willett 2013a), in which household food group or nutrient consumption was regressed in a linear model upon the four predictors, and the residuals were extracted and scaled by adding to them the mean of household consumption across all households, producing residual-adjusted measures of daily household consumption (negative values of household consumption resulting from this adjustment were set to 0 for interpretability). The AME method was then applied to each household survey by multiplying each household's residual-adjusted food group and nutrient consumption by the household's total caloric requirement. Disaggregated estimates of food and nutrient consumption density were derived by dividing each household member's AME-disaggregated food or nutrient consumption estimates by their AME-disaggregated energy consumption estimate and multiplying by 100. A survey-weighted mean of consumption and consumption density of each food group and nutrient was then computed within each age group and sex (in the case of nutrient densities, a trimmed mean was taken to provide results robust to extreme ratios). Disaggregated household consumption estimates were smoothed across the 10 age groups within each sex using the same approach as in the statistical method.

Comparison between disaggregated household consumption estimates and individual dietary intake measurements (Aims 2 and 3)

Validity of each disaggregation method was evaluated based on its ability to estimate dietary food group and nutrient intake and intake densities of individuals by comparing disaggregated household consumption estimates from the HSES-HH and FCS-HH with within-person variance-adjusted individual dietary measurements from the nested FCS-24. Three validation metrics (bias, coverage probability, and ability to rank consumption) were derived for each disaggregation method (statistical and AME), food group and nutrient, class of estimate (consumption and consumption density), and household survey (FCS-HH and HSES-HH). While statistical- and AME-disaggregated household consumption estimates are computed using survey weights, FCS-24 measurements are not weighted, therefore each of the three validation metrics implicitly account for survey weights and are nationally-representative statistics.

(1) Bias (observed – predicted value) was calculated for each of the 1,356 individuals analyzed in the FCS-24, between (a) the individual's 24HR dietary intake or intake density measurement and (b) the corresponding statistical or AME disaggregated household estimate predicted for the individual based on their age group and sex. Mean bias was calculated for each food group or nutrient and within both the FCS-HH and HSES-HH by averaging bias over all 1,356 individuals.

(2) Coverage probability, calculated as the proportion of FCS-24 dietary intake or intake density measurements contained within the 95% confidence limits of the estimate predicted by each of the two household consumption disaggregation methods based on each individuals' age and sex, was assessed across all 1,356 individuals analyzed in the FCS-24.

(3) For both the statistical and AME methods, disaggregated household consumption and consumption density estimates for each of the 14 age-sex groups captured by the FCS-24 sample (i.e. not including males and females aged 0-4, 5-9, and 10-14 years, which were represented in HSES-HH and FCS-HH but not in the nested FCS-24) was assigned a rank from 1 to 14. From each rank was subtracted the rank of mean observed dietary intake or intake density for the same age-sex group in the FCS-24 to produce an age- and sex-specific absolute rank bias. Mean absolute rank bias was then calculated for each of the two disaggregation methods by averaging absolute rank bias across the 14 age-sex groups.

An additional set of the same three validation metrics were derived for each dietary component and age-sex group after applying an adjustment to the original statistical disaggregation method (hereby referred to as the "unadjusted" statistical disaggregation method and denoted as "SD1" in tables). Conceptually, the adjustment involves a hybridization of the statistical and AME disaggregation approaches to produce "AME-like" ("SD2") estimates, by interpreting SD1's parameter estimates not as proxies for absolute dietary intake but instead as empirical coefficients for weighting relative consumption of observed household foods and nutrients (analogous to the AME's method of weighting household consumption according to relative energy requirements). Equations describing the AME SD1, and SD2 methods are given in Appendix F.

Aim 4: Direct prediction of dietary nutrient intake by individuals

In contrast to statistical disaggregation (prediction of household consumption to infer that of individuals), an alternate statistical approach was evaluated among the 1,356 individuals participating in the FCS-24, in which individual dietary nutrient intakes and intake densities (adjusted for within-person variance) were directly predicted using a progressively more expansive set of household- and individual-level covariates. The purpose of this analysis was to assess – given the availability of household characteristics, individual characteristics, and individual dietary measurements for the same participants with which to train a model – the accuracy with which a household consumption and expenditure survey could predict individuals' dietary nutrient intakes and intake densities and the relative importance of different categories of predictors. Seven such categories were evaluated in a cumulative fashion, such that the simplest model considered variables in only 1 category for potential inclusion, and the most complex considered 5 categories. Categories were added in order of increasing difficulty and invasiveness to collect, thus providing what may be considered a more realistic hierarchy of category combinations which would be considered for assessment in an actual survey. Regularized (elastic net) regression was used to evaluate a large number of potentially significant predictors while minimizing over-fitting (R v3.4 ‘glmnet’ package) using a natural logarithm transformation of nutrient intakes and intake densities to account for their right skew (Friedman 2010). In an alternate analysis more comparable to that of the SD and AME disaggregation methods, nutrient intake densities were also predicted by dividing the predicted value of each nutrient intake by the predicted value of energy intake and multiplying by 100.

For each model, shrinkage and elastic net mixing parameters λ and α were selected through nested 10-fold cross validation (the inner and outer loops of which selected λ and α values, respectively, which minimized model mean square error), using the same folds to validate λ for each value of α as recommended by glmnet documentation. Percentage of deviance explained and mean absolute error were obtained for each model at optimal λ and α values (mean absolute error of statistical- and AME-disaggregated household estimates were also calculated for comparison). For simplicity, only in-sample fit statistics were estimated rather than incorporating a third cross-validation loop on held-out test sets; fit statistics are therefore expected to be slightly optimistic.

Results

Characteristics of study populations

Characteristics of the FCS-HH and HSES-HH study populations are provided in Table 3.1. The HSES-HH oversampled households in provincial and county centers while the FCS-HH sample more closely resembled the Mongolian population with respect to urban vs. rural locality. This difference is associated with other differences in the distributions of household size (mean: 4.0 in the FCS-HH vs. 3.3 in the HSES-HH) educational household attainment (the distribution of which was substantially narrower in the FCS-HH), family composition (single-person households were less common in the FCS-HH (7.2%) than the HSES-HH (13.1%), as was living with one's spouse or partner (40.5% vs. 50.6%)), and the reported proportions of total household energy expenditure from impermanent members (1.81% and 2.5% in the FCS-HH and HSES-HH, respectively) and food spending outside home (12.1% and 9.1%, respectively). Mean age of household members was similar in the FCS-HH and HSES-HH samples (28.7 and 28.4 years, respectively).

The use of survey weights based on urban vs. rural locality and national province are expected to compensate for some, but not all of the effect of these differences in applicable statistical analyses.

Proportions of households in the HSES-HH and FCS-HH and individuals in the nested FCS-24 observed to consume each food group and nutrient are provided in Table S3.3. For four nutrients in the FCS-24R, the proportion of individuals observed to consume them was less than 99% (alcohol (3.5%) and vitamins C (96.8%), A (96.9%), and D (93.8%)), while 20% and 11.3% of households in the FCS-HH and HSES-HH, respectively, reported any household consumption of alcohol. The proportion of individuals in the FCS-24 observed to consume any of each food group ranged from 20.1% (sugar and sweeteners) to 97.1% (meat/fish/poultry), while the proportion of observed household consumption of all food groups exceeded 90% in the FCS-HH and was less than 90% for four food groups in the HSES-HH: animal fat/eggs/dairy products (87.8%), baked and fried flour products (85.1%), starchy root vegetables (82.5%), and vegetable oils (82.5%). Correlation between consumed items was generally much higher in the FCS-HH than the FCS-24, and was higher between nutrients than between food groups in both datasets (Table S3.4).

Aim 1: Direct comparison between per-capita household consumption and per-capita dietary measurements from the same households

Figures 3.2 and S3.1, and Table S3.5 compare mean per-capita household consumption and consumption density (per 100 kcal) of food groups and nutrients (derived from household recall measurements) with paired per-capita 24-hour recall measurements collected from the same 63 multi- and 46 single-person FCS-HH households fully-enumerated by the nested FCS-24. Figure 3.2 summarizes the results of this analysis for food groups and selected nutrients which may be considered generally more relevant to nutrition surveillance in developing countries, while Table S3.5 provides the results in full. Household-derived mean consumption overestimated dietary-derived mean intake of almost all food groups considered among members of both multi-person and single-person households, the overestimation being especially prominent among the latter. For all but two dietary components presented in Figure 3.2 (meat/fish/poultry and starchy root vegetables), the ratio of per-capita household- to dietary-derived means was consistently larger among single-person households. Per-capita household consumption measurements overestimated mean per-capita energy intake among multi- and single-person households by factors of 1.89 and 2.63, respectively. Across food groups, only dietary intake of baked and fried flour products, flours/grains/and noodles, and milk among multi-person households, and meat/fish/poultry and milk among single-person households were overestimated by factors smaller than 1.4, while dietary intake of sugar and sweeteners among single-person households and fruits and non-tuberous vegetables among both households types were overestimated by factors greater than 5.5. Correlation and rank correlation generally ranged from low to practically indiscernible across food groups and nutrients (correlation between per-capita energy estimates was 0.29 and 0.09 among multi- and single-person households, respectively) (Figure S3.1, Table S3.5). Only in the case of fruits and non-tuberous vegetables' among multi-person households, and alcohol among both types of households did correlation between household- and dietary-derived per-capita estimates exceed 0.50.

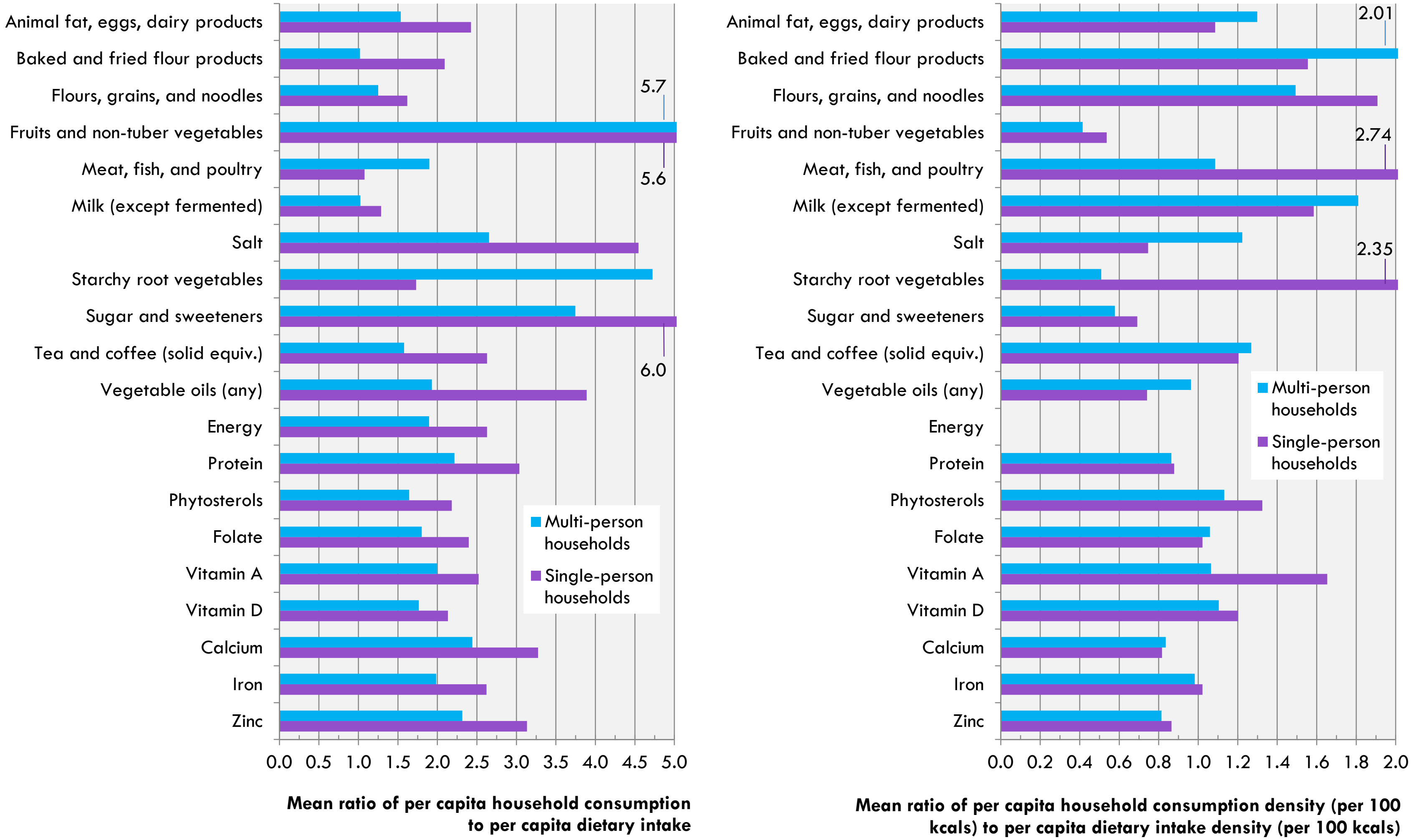


Figure 3.2: Mean ratio of per-capita household consumption to per-capita dietary intake (left), and per-capita household consumption density (per 100 kcal) to per-capita dietary intake density (per 100 kcal) (right) for food groups and selected nutrients among 109 FCS-HH households fully-enumerated by the nested FCS-24 (Aim 1). Values for 6 data points exceed the graphs' x-axis limits and are indicated using annotations. Abbreviations: FCS-HH (2013 Food Consumption Survey), FCS-24 (nested 24-hour recall).

With the two exceptions of phytosterols and vitamin A in multi-person households, the mean of each household-derived per-capita household consumption density (per 100 kcal) of all nutrients presented in Figure 3.2 lied within ±10% of its corresponding dietary-derived mean. Conversely, food groups displayed a wide range of variation in the ratio of mean per-capita household- and dietary-derived density estimates, though generally less so than in the case of energy-unadjusted estimates, and without the same pattern of overestimation among single-person households relative to multi-person households (or overestimation overall) seen in the energy-unadjusted results.

Aims 2 and 3: Comparison between disaggregated household consumption estimates and individual dietary intake measurements

Mean bias in the application of each household disaggregation method to the FCS-HH and HSES-HH is presented in Table 3.2 and summarized graphically for food groups and selected nutrients in Figure S3.2. In comparison with FCS-24 dietary measurements, the unadjusted statistical method (SD1) proved more accurate than the AME method in disaggregating daily household consumption in the FCS-HH for most food groups and nutrients (mean bias in estimating individuals' dietary energy intake for the SD1 and AME methods was +163 and +1088 kcal/day, respectively, or +8.7% and +58.0% with respect to the grand mean of dietary energy intake). Both methods tended to overestimate consumption of most dietary components in the FCS-HH, particularly in the case of the AME method. In contrast, the application of the unadjusted statistical method to the HSES-HH produced severe underestimates of dietary energy intake (mean bias: -918 kcal/day), while the AME method still tended to overestimate albeit to a lesser degree than in its application to the FCS-HH (mean bias: +302 kcal/day). In terms of mean bias, the statistical method performed more accurately than the AME method in estimating individuals' dietary intake of 8 of 11 food groups but only 4 of 27 nutrients in the HSES-HH. In estimating dietary intake densities, the SD1 method significantly outperformed the AME method in both surveys, producing a smaller absolute mean bias for all but 4 or 37 dietary components in the FCS-HH and 3 in the HSES-HH. In disaggregation of both household surveys, the SD2 adjustments produced improvements in disaggregation intakes in the HSES-HH but not the FCS-HH, and increased bias in intake densities in disaggregating both surveys.

Table 3.2: Mean bias of disaggregated household consumption estimates of individuals' food group and nutrient intake and intake density (per 100 kcal) across 14 age-sex groups (Aims 2 and 3)

	Validation Metric:	**Mean Bias in Intake**							**Mean Bias in Intake Density (per 100 kcal)**						
	Household Survey:		**FCS-HH (n=1012)**			**HSES-HH (n=9424)**				**FCS-HH (n=1012)**			**HSES-HH (n=9424)**		
	Disaggregation Method:	**Intake**	**SD1**	**SD2**	**AME**	**SD1**	**SD2**	**AME**	**Density**	**SD1**	**SD2**	**AME**	**SD1**	**SD2**	**AME**
Food Groups	Animal fat, eggs, and dairy products (g)	92.1	-6.3	109.7	128.6	-61.9	-13.2	16.2	4.90	-0.72	1.19	5.44	-1.32	-1.16	3.41
	Baked and fried flour products (g)	115.0	-16.2	64.1	63.6	-75.0	0.3	19.6	6.06	-1.23	-0.54	2.22	-1.62	-0.57	4.09
	Flours, grains, and noodles (g)	231.9	-29.7	49.0	64.1	-146.8	-48.6	-38.8	12.06	-1.75	-2.99	1.17	-2.96	-3.29	-0.17
	Fruits and non-tuber vegetables (g)	31.6	9.1	101.5	90.0	-7.7	42.7	57.2	1.77	0.27	2.57	5.09	0.63	1.94	5.17
	Meat, fish, and poultry (g)	114.4	2.7	126.7	89.0	-47.6	50.7	53.4	5.88	-0.14	1.67	2.77	0.99	1.87	3.97
	Milk (except fermented) (g)	77.9	36.3	232.6	189.6	0.4	133.2	148.7	4.18	1.38	5.33	8.21	3.94	5.23	9.69
	Salt (g)	1.8	2.8	6.7	6.0	-0.3	3.2	3.5	0.10	0.14	0.17	0.38	0.07	0.14	0.34
	Starchy root vegetables (g)	30.7	35.4	75.7	82.4	-0.8	28.3	42.9	1.69	1.61	1.70	5.02	1.44	1.15	4.19
	Sugar and sweeteners (g)	3.6	7.6	14.1	16.9	4.3	13.7	14.8	0.20	0.35	0.35	0.79	0.63	0.61	1.18
	Tea or coffee (solid equivalent) (g)	3.6	-1.0	1.8	1.8	-1.1	2.4	2.2	0.20	-0.07	-0.02	0.13	0.03	0.08	0.31
	Vegetable oils (any) (g)	6.6	1.3	8.7	8.9	-2.5	2.7	5.4	0.33	0.05	0.14	0.43	0.09	0.10	0.69
Macronutrients	Energy (kcal)	1864	163	1335	1088	-918	267	302	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Carbohydrates (g)	241.10	19.13	132.57	123.41	-127.89	4.79	16.54	12.920	0.052	-1.166	0.890	-0.783	-1.295	0.669
	Protein (g)	70.09	7.54	64.14	49.69	-32.71	18.11	18.35	3.777	0.032	0.377	0.319	0.192	0.362	0.637
	Total fat (g)	66.38	3.62	67.62	47.04	-29.79	20.24	21.98	3.574	-0.194	0.523	0.220	0.235	0.471	0.268
	Alcohol (g)	1.47	-1.23	-0.90	-0.51	-1.46	-0.88	-0.18	0.067	-0.049	-0.055	0.204	-0.048	-0.040	0.441
	Water (g)	572.27	96.92	704.75	558.11	-208.99	335.68	325.36	31.081	1.629	8.337	11.702	6.622	11.052	18.846
	Fiber (g)	8.6	1.6	6.4	5.8	-4.0	0.8	1.4	0.47	0.04	0.01	0.11	0.03	-0.01	0.10
	Phytosterols (mg)	424	104	309	256	-229	-22	-9	22.9	3.6	0.2	3.7	-1.9	-3.8	0.5
Vitamins	Thiamin (mg)	0.784	0.164	0.723	0.563	-0.318	0.228	0.278	0.0426	0.0043	0.0045	0.0073	0.0071	0.0054	0.0148
	Riboflavin (mg)	1.220	0.184	1.225	0.990	-0.486	0.463	0.484	0.0661	0.0033	0.0103	0.0127	0.0097	0.0119	0.0216
	Niacin (mg)	13.064	2.539	12.945	9.419	-5.335	3.891	4.392	0.7093	0.0625	0.1066	0.1304	0.1044	0.0910	0.2470
	Pantothenic acid (mg)	3.111	0.668	3.099	2.383	-1.238	1.218	1.146	0.1686	0.0176	0.0247	0.0240	0.0265	0.0336	0.0406
	Vitamin B6 (mg)	0.628	0.150	0.684	0.534	-0.279	0.170	0.187	0.0342	0.0044	0.0071	0.0124	0.0022	0.0036	0.0119
	Folate (µg)	132	4	95	76	-65	21	27	7.1	-0.4	0.0	0.2	0.2	0.1	1.2
	Vitamin B12 (µg)	6.35	-0.85	2.29	1.98	-3.00	0.48	0.54	0.339	-0.058	-0.057	0.019	-0.007	-0.021	0.036
	Vitamin C (mg)	12.4	4.1	24.0	20.7	-3.4	10.0	12.6	0.70	0.12	0.45	1.00	0.26	0.39	0.99
	Vitamin A (µg)	448	-112	187	173	-200	-2	54	23.7	-6.6	-2.8	6.5	0.6	-2.5	4.7
	Vitamin D (IU)	26	1	30	22	-12	10	12	1.4	-0.1	0.3	0.6	0.0	0.3	0.4
	Vitamin E (mg)	5.28	0.24	5.24	4.33	-2.68	0.92	1.57	0.286	-0.016	0.040	0.113	-0.008	0.010	0.137
Minerals	Calcium (mg)	432	100	544	466	-151	255	288	23.6	2.4	6.4	9.2	5.8	8.1	13.6
	Copper (mg)	0.986	0.097	0.600	0.483	-0.447	0.100	0.119	0.0528	0.0019	-0.0019	0.0065	0.0035	-0.0010	0.0078
	Iron (mg)	10.03	1.07	7.47	5.84	-4.73	1.53	1.92	0.541	0.009	0.007	0.044	0.027	0.006	0.102
	Magnesium (mg)	168	29	141	115	-77	41	41	9.1	0.7	0.6	1.0	0.6	0.8	1.6
	Manganese (mg)	2.172	0.196	1.308	1.220	-0.998	0.394	0.434	0.1171	0.0008	-0.0075	0.0193	0.0073	0.0040	0.0347
	Phosphorus (mg)	907	93	835	660	-446	200	211	48.9	0.4	5.1	3.5	0.4	2.8	5.8
	Potassium (mg)	1436	207	1637	1209	-620	625	591	78.1	2.1	16.7	18.0	7.7	18.7	27.5
	Zinc (mg)	10.85	0.91	11.20	7.80	-4.97	3.58	3.52	0.587	-0.011	0.096	0.084	0.030	0.086	0.159

Table 3.2 (continued)

Mean dietary intake and intake density estimates from the FCS-24 are provided for better interpretability of mean bias in disaggregated estimates. Green-Yellow-Red shading indicates the magnitude of absolute mean bias in estimated intake in proportion to mean intake (Green: minimum observed absolute mean bias; yellow: median; red: maximum), and Blue-Yellow-Red shading indicates the magnitude of absolute mean bias in estimated intake density in proportion to mean intake density (Blue: minimum observed absolute mean bias; yellow: median; red: maximum). Statistics are survey weighted. Abbreviations: FCS-HH (2013 Food Consumption Survey), FCS-24 (nested 24-hour recall), HSES-HH (2012/2014 Household Socio-Economic Survey), SD1 (unadjusted statistical disaggregation method), SD2 (AME-like statistical disaggregation method), AME (adult male equivalent method), IU (international unit; 40 IU = 1 μg).

Coverage probability (the proportion of FCS-24 intake measurements falling within the 95% confidence bounds of their corresponding household-disaggregated consumption estimate for the same age-sex groups) was considerably higher for the statistical methods than the AME method for disaggregating nutrient consumption in both surveys, with SD1 outperforming in the FCS-HH and SD2 generally outperforming in the HCES-HH (Table 3.3). The ability of disaggregation methods to rank dietary intake was generally poor (Table S3.7). Application of the SD1 method to the HSES-HH produced a smaller mean absolute bias than the AME method in assigning ranks of dietary intake across the 14 age-sex groups captured by the FCS-24 for 8 of 11 food groups, and a smaller or equal mean absolute rank bias for 15 of 27 nutrients,, while SD1's application to the FCS-HH produced a larger mean absolute rank bias for 8 of 11 food groups and all nutrients. In attempting to derive ranks of mean intake *density*, relative performance of the SD1 method generally improved, while the SD2 did not produce a discernible benefit to absolute bias in ranks of in intake or intake density in disaggregation of either survey.

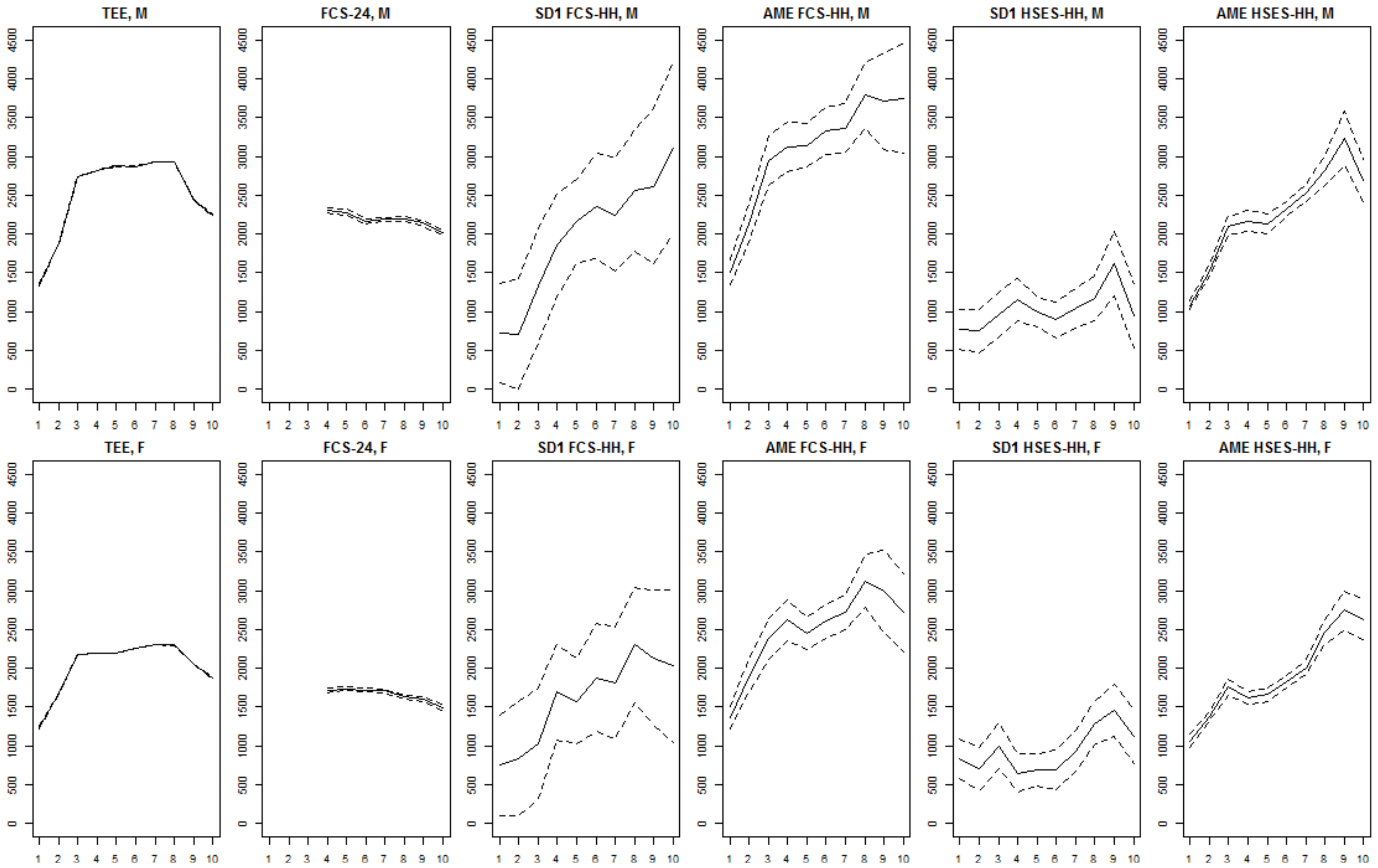
Table 3.3: Coverage probability of household disaggregation methods across 14 age-sex groups (mean % of observed dietary nutrient intakes or intake densities (per 100 kcal) lying within 95% confidence interval of corresponding disaggregated household consumption estimate) (Aims 2 and 3)

	Validation Metric:	**Nutrient Intake Coverage Probability**				**Nutrient Density Coverage Probability**			
	Household Survey:	**FCS-HH (n=1012)**		**HSES-HH (n=9294)**		**FCS-HH (n=1012)**		**HSES-HH (n=9294)**	
	Disaggregation Method:	**SD1**	**SD2**	**AME**	**SD1**	**SD2**	**AME**	**AME**	**AME**
Macronutrients	Energy (kcal)	88.5	13.2	3.0	10.4	37.5	13.8	N/A	N/A
	Carbohydrates (g)	76.7	25.8	5.2	3.2	23.2	10.7	37.0	17.8
	Protein (g)	79.9	18.0	2.0	8.1	24.1	8.1	24.2	2.8
	Total fat (g)	79.1	26.4	5.3	33.1	46.4	16.1	27.9	8.6
	Alcohol (g)	45.4	26.4	27.5	37.8	32.2	7.4	1.6	0.1
	Water (g)	71.5	20.3	3.9	21.8	10.8	3.2	8.9	2.4
	Fiber (g)	76.3	12.4	2.0	6.8	32.6	11.4	13.4	6.0
	Phytosterols (mg)	72.5	18.9	2.7	3.4	23.2	16.3	22.0	29.3
Vitamins	Thiamin (mg)	71.0	13.5	2.5	16.0	28.7	7.0	17.4	1.6
	Riboflavin (mg)	79.5	23.4	2.7	16.8	21.2	5.0	14.8	2.0
	Niacin (mg)	75.9	7.0	1.6	10.5	25.2	5.1	21.4	1.4
	Pantothenic acid (mg)	71.3	14.0	2.5	15.5	17.4	4.7	19.1	2.4
	Vitamin B6 (mg)	71.0	10.7	2.7	13.0	20.8	5.4	10.5	3.5
	Folate (µg)	80.8	24.3	6.7	9.1	23.7	8.1	24.6	5.5
	Vitamin B12 (µg)	71.6	40.7	12.0	20.9	23.9	15.0	23.8	7.1
	Vitamin C (mg)	84.6	14.9	0.6	50.3	9.6	0.7	1.6	0.1
	Vitamin A (µg)	69.3	30.8	12.3	59.0	49.4	13.6	9.7	3.0
	Vitamin D (IU)	76.2	28.6	4.5	67.0	47.1	13.4	13.8	7.9
	Vitamin E (mg)	81.9	24.3	3.6	11.1	38.2	11.1	11.5	2.7
Minerals	Calcium (mg)	80.2	25.7	5.1	30.5	17.2	4.4	10.7	1.8
	Copper (mg)	63.8	21.0	7.6	12.5	26.4	10.1	18.0	6.2
	Iron (mg)	77.2	15.1	3.3	6.8	27.3	8.2	31.0	2.7
	Magnesium (mg)	68.4	14.2	2.4	11.5	22.9	9.4	17.4	2.7
	Manganese (mg)	78.4	19.7	2.9	8.1	27.0	9.7	24.8	2.2
	Phosphorus (mg)	79.7	16.9	2.7	9.6	23.9	9.9	25.3	5.6
	Potassium (mg)	74.4	15.4	1.8	15.4	14.6	4.1	10.4	0.8
	Zinc (mg)	82.3	16.6	1.9	7.9	26.2	7.3	21.8	1.9

Shading indicates the magnitude of estimated mean coverage probability (Green: maximum estimated coverage probability; yellow: median; red: minimum). Mean coverage probability is omitted for statistical (SD1) and AME-like (SD2) nutrient intake densities given the complexity of deriving standard errors for the corresponding ratio estimators. Abbreviations: Abbreviations: FCS-HH (2013 Food Consumption Survey), HSES-HH (2012/2014 Household Socio-Economic Survey), SD1 (unadjusted statistical disaggregation method), SD2 (AME-like statistical disaggregation method), AME (adult male equivalent method), IU (international unit; 40 IU = 1 µg). Statistics are survey weighted.

Figure 3.3 compares mean daily estimated energy expenditure, mean observed dietary energy intake, and disaggregated household consumption estimates of individuals' energy intake derived from the application of the SD1, SD2, and AME disaggregation methods to the FCS-HH and HSES-HH across 10 age groups of males and females. Estimated energy expenditure among males and females exceeded observed dietary intake in all of the age groups for which dietary intake measurements were available. Unlike estimated energy expenditure, graphs of observed dietary energy intake are relatively flat despite a slight decrease with age, while disaggregated household consumption estimates are considerably wigglier. In both the FCS-HH and HSES-HH, the standard errors confidence limits of AME-disaggregated estimates are considerably narrower than those of statistical disaggregation estimates for the same age-sex groups.

Figure 3.3: Comparison between mean daily estimated energy expenditure, observed dietary energy intake, and disaggregated household consumption estimates of individuals' energy intake (kcal/day) across 10 age groups of males and females (Aims 2 and 3)



y-axis: daily energy intake (kcal/day); **x-axis:** age groups 1-10 (1: 0 to 4 years, 2: 5-9, 3: 10-14, 4: 15-19, 5: 20-29, 6: 30-39, 7: 40-49, 8: 50-59, 9: 60-69, 10: 70+); **row 1:** males ("M"); **row 2:** females ("F"); **column 1:** mean predicted total energy expenditure ("TEE"), **column 2:** mean observed dietary energy intake from the FCS 24-hour recall ("FCS-24"); **column 3:** unadjusted statistical disaggregation of FCS-HH ("SD1 FCS-HH"); **column 4:** AME-like statistical disaggregation of FCS-HH ("SD2 FCS-HH"); **column 5:** AME disaggregation of FCS-HH ("AME FCS-HH"); **column 6:** unadjusted statistical disaggregation of HSES-HH ("SD1 HSES-HH"); **column 7:** AME-like statistical disaggregation of HSES-HH ("SD2 HSES-HH"); **column 8:** AME disaggregation of HSES-HH ("AME HSES-HH"). **Solid lines** indicate means of age- and sex-specific measurements (FCS-24) or predictions (TEE and disaggregated household estimates), while **dashed lines** indicate associated 95% confidence limits. Statistics *are* survey-weighted. Abbreviations: FCS-HH (2013 Food Consumption Survey), HSES-HH (2012/2014 Household Socio-Economic Survey), AME (adult male equivalent method).

Goodness of fit of statistical disaggregation models are provided in Table S3.6. FCS-HH and HSES-HH disaggregation models explained 35.0% and 34.1% of deviance in household energy consumption, respectively (mean absolute error = 3,269 and 2,418 kcal/day, respectively, or 30.4% and 33.6% of the grand mean of household energy consumption).

Aim 4: Direct prediction of dietary nutrient intake by individuals

Table 3.4 summarizes the seven sets of variables considered for potential selection in each of seven increasingly complex prediction models of dietary nutrient intakes and intake densities by individuals in the FCS-24. Detailed in-sample fit statistics for these models are presented in Table S3.8 and S3.9, and graphically in Figures 3.4 (intakes) and S3 (intake densities) for a subset of nutrients generally more relevant to surveillance in developing countries. The most basic model (Model 1), incorporating only household and individual demographic, socioeconomic, and lifestyle variables, explained 53.6% of daily caloric intake with a mean absolute bias of 229 kcal/day (compared with 384 and 1095 kcal/day from SD1 and AME disaggregation of the FCS-HH, respectively) (Figure 3.4, Table S3.8). Increasing model complexity by adding household food group and nutrient intake (Model 2) and/or individual nutrition knowledge (Model 3) to the pool of selectable variables produced modest increases in the predictive ability ($\geq$+4% deviance explained) for total fat, certain vitamins (riboflavin, vitamin B12, vitamin C, and vitamin A), and calcium, while effects on other macronutrient and micronutrients prediction were smaller (Figure 3.4, Table S3.8). The marginal benefit of including measured anthropometry (Model 5) was generally small to negligible. Occasionally, addition of these variables (household consumption, nutrition knowledge, measured anthropometry) to the pool of potential predictors appeared to “confuse” model selection and result in slightly poorer model fit.

Table 3.4: Categories of household- and individual-level variables considered for selection in predictive models of individuals' dietary nutrient intakes and intake densities in the FCS-24 (Aim 4)

Category	Variables comprised by each category	Models in which each category was considered for selection						
		1	2	3	4a	4b	4c	5
Household and individual demographic, socioeconomic, and lifestyle characteristics	Household-level variables: Weekday of assessment; province and location (capital, provincial/county center, rural) of household; numbers of men, women, boy, and girl household members; presence of students, herders, pensioners, married men or women, and members of the agricultural, industrial, or service industries in the household; total household income; average daily value of all foods consumed by the household; average daily value of foods eaten outside home; sum and maximum of household members' years of education; household family composition; average daily energy expenditure of all household members; average daily energy expenditure of all guests and visitors. Individual-level variables: Age, sex, relationship to head of household, marriage status, current pregnancy or lactation, years of education, occupation, industry of employment, any food allergy, self-evaluated physical activity level; overall health, presence of any metabolic disease, and presence of any other serious disease in past 6 months.	✓	✓	✓	✓	✓	✓	✓
Quantitative total household consumption of food groups and nutrients	Household-level variables: Average daily quantitative household consumption of 12 food groups and 27 nutrients from all sources combined (purchased, produced at home, and received as gifts).		✓	✓	✓	✓	✓	✓
Individuals' self-evaluation of nutrition knowledge and its application to their lives	Individual-level variables: "Qualitatively evaluate your bodyweight"; "Do you know of and understand the Mongolian national dietary guidelines?"; "Do you understand the importance of dietary diversity?", "Do you understand the importance of eating regularly?"; "Do you try to cook with and eat less sugar and sugary foods, less fat and fatty foods, more fresh foods, more fruits, and more vegetables?", "Do you understand what a healthy and balance diet is?"; "How would you evaluate the quality your diet?"; "Do you understand that nutrition is important for health maintenance, or for your child's health?", "How important is your nutrition knowledge to your health?"; "How do you evaluate your nutrition knowledge?"; "Do you pay attention to each of the following: nutrition facts, ingredient labels, health claims, expiration dates"; "Have you attended any nutrition training?"; "Do you take any nutritional supplements?".			✓	✓	✓	✓	✓

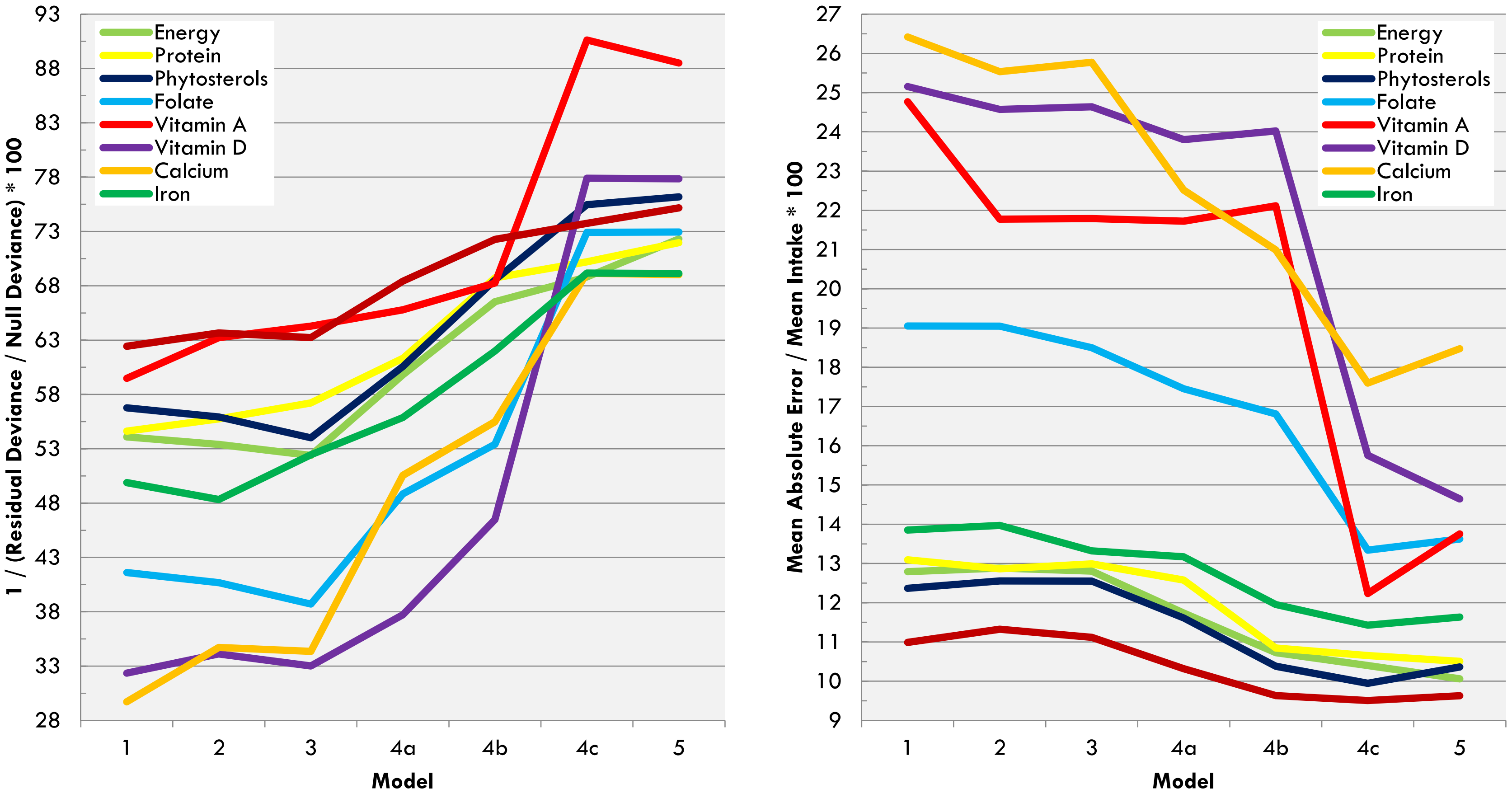
Table 3.4 (continued)

		Models in which each category was considered for selection						
Category	**Variables comprised by each category**	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**
Cursory qualitative 24-hour recall and assessment of eating behaviors	Individual-level variables: Binary (yes or no) consumption of 12 food groups yesterday; "Did you ever out in the past year?"; "Did you skip any meals in the past 2 days?"; "Did you miss any meals with your family yesterday?"; "Did you eat more, less, or the same amount today as yesterday?"; "Did you eat any foods outside home yesterday?"; "Did you miss any meals yesterday (breakfast, lunch dinner)?"; "Did you eat any snacks yesterday?".				✓			
Cursory semiquantitative 24-hour recall and assessment of eating behaviors	Individual-level variables: Number of foods eaten yesterday from each of 12 food groups; frequency of snack consumption and eating out in the past year; number of meals (breakfast, lunch, dinner) skipped in last 2 days; "Did you eat more, less, or the same today as yesterday?"; sum of meals (breakfast, lunch, dinner) eaten with family yesterday; total number of food items eaten in each of the following places yesterday: home, outside, someone else's house, elsewhere; total number of food items eaten yesterday for each meal (breakfast, lunch, dinner) and as snacks.					✓		
Detailed semiquantitative 24-hour recall	Individual-level variables: Binary (yes or no) consumption of 136 different foods during the past 24 hours.						✓	✓
Measured anthropometry	Individual-level variables: Measured height and weight; body-mass index; measured waist, hip, mid-arm, and wrist circumference.							✓

Models designated 1-5 correspond to those described in detail in Table 3.4. Brief description of variable categories considered for selection in each model: (1) Household and individual demographic, socioeconomic, and lifestyle characteristics, (2) Model 1 variables + quantitative total household consumption of food groups and nutrients, (3) Model 2 variables + individuals' self-evaluation of nutrition knowledge and its application to their lives, (4a) Model 3 variables + cursory qualitative 24-hour recall and assessment of eating behaviors, (4b) Model 3 variables + cursory semiquantitative 24-hour recall and assessment of eating behaviors, (4c) Model 3 variables + detailed semiquantitative 24-hour recall, (5) Model 4 variables + measured anthropometry. Number of observations analyzed in each model: 1 and 2 (1282); 3 and 4b (1142); 4a (1140); 4c (1129); 5 (1056). Abbreviation: FCS-24 (nested 24-hour recall of the 2013 Food Consumption Survey).

The largest and most consistent marginal improvements to model fit were incurred upon inclusion of cursory qualitative, cursory semiquantitative, or detailed semiquantitative assessment of diet and eating behaviors (Models 4a-4c), particularly for micronutrients. For example, in the case of calcium, addition of cursory qualitative, cursory semiquantitative, or detailed semiquantitative diet variables to model selection resulted in a 16.2%, 4.9%, and 13.7% increase in deviance explained, respectively, and an overall 34.8% net decrease in mean absolute error relative to the grand mean of calcium intake in the FCS-24 (Figure 3.4, Table S3.8). In the majority of cases, the accuracy with which the same model predicted dietary intake densities for a given nutrient (in terms of deviance explained) was poorer than that of predicting intakes, especially prior to the addition of detailed semiquantitative diet variables. Nonetheless, for all nutrients, mean absolute error of even the simplest intake density prediction models (Model 1) was less than those of the statistical and AME disaggregation methods. Results were similar for alternate prediction nutrient density prediction models based on separate prediction of nutrient intake and energy intake (Figure S3.3 and Table S3.9).

Figure 3.4: In-sample fit statistics for increasingly complex predictive models of individuals' dietary intakes of selected nutrients in the FCS-24 (Aim 4)



See Table 3.4 for detailed descriptions of models 1-5. Brief description of variable categories considered for selection in each model: (1) Household and individual demographic, socioeconomic, and lifestyle characteristics, (2) Model 1 variables + quantitative total household consumption of food groups and nutrients, (3) Model 2 variables + individuals' self-evaluation of nutrition knowledge and its application to their lives, (4a) Model 3 variables + cursory qualitative 24-hour recall and assessment of eating behaviors, (4b) Model 3 variables + cursory semiquantitative 24-hour recall and assessment of eating behaviors, (4c) Model 3 variables + detailed semiquantitative 24-hour recall, (5) Model 4 variables + measured anthropometry. Abbreviation: FCS-24 (nested 24-hour recall of the 2013 Food Consumption Survey).

Note: The number of significant figures reported in estimates of and bias in dietary intake and household consumption of nutrients reflect the precision of laboratory analytical measurements of nutrient concentrations, while the number of significant figures in estimates of and bias in nutrient intake and consumption densities (per 100 kcal) is deliberately increased by 1 for ease of interpretation. Statistics are not survey-weighted unless indicated otherwise.

Discussion

Given the dearth of detailed, periodic dietary intake data for much of the world's population and the volume of food consumption data present in household consumption and expenditure (HCE) surveys, the potential value of HCE data to nutrition research and surveillance is immense, particularly for developing countries. In recognition of this, recent decades have seen steadily growing interest in survey design and analytical approaches geared toward increasing the applicability of HCE data in nutrition (Trichopolou 1997, Fiedler 2013a, Zezza 2017). This effort is challenged by the fact that household food and nutrient consumption are far from perfect proxies for individuals' diets, the primary exposure of interest in nutritional epidemiology and one which remains difficult to assess with great accuracy even under the best of conditions. Nonetheless, necessity is the mother of invention, and some interesting ways to meet this challenge have suggested themselves in the literature, four of which are evaluated in this paper.

Aim 1: Direct comparison between per-capita household consumption and per-capita dietary measurements from the same households

The first and simplest approach involves direct inference of dietary intake based on per-capita household food consumption (Friel 2001, Naaska 2001a, Becker 2001, Sekula 2005). Accurate household consumption measurements are a prerequisite for accuracy of the AME and statistical disaggregation methods evaluated in this paper; for the purpose of directly assigning dietary intake to individuals, per-capita household consumption measurements are less useful for multi-person households because they imply impossibly equitable intra-household distribution of food. Because persons living by themselves are the main consumers of food in their household (with the exception of guest and visitors), household food consumption may be an appropriate proxy for these individuals' dietary intakes, although the degree to which these estimates are generalizable to those living in multi-person households may be limited. In the current study, we found household food group and nutrient consumption among 109 FCS-HH households fully-enumerated by the FCS-24 to overestimate and correlate poorly with dietary intake in both types of households, especially single-person households.

Important sources of systematic and random error are known to influence reporting of household food consumption data (Smith 2014) and have more recently been subject to more formal decomposition (Friedman 2017). In particular, the magnitude of overestimation in the FCS-HH suggests that enumerators provided telescoped estimates (their recall included household foods consumed prior to the reference period) (Willett 2013b, Friedman 2017). It is also plausible that reported household food consumption was partly conflated with food that was acquired (or simply present in household stocks) over the reference period but that not necessarily consumed, or was perhaps transferred to other households. It is not immediately clear why over-reporting would affect multi-person households to a lesser extent than single-person households, but this may have to do with accuracy incurred by the cognitive exercise of distinguishing and dividing consumption among each household member in a multi-person household, while those living alone might rely on less enumerative rules-of-thumb. Recall error is mitigated by the use of prospective instruments such as the HSES-HH's consumption diary, but these are conversely more likely to be affected by underreporting due to respondent burden (Troubat 2017). Efforts to improve the accuracy of reported household food consumption are ongoing and have considered such cognitive and survey design (Fiedler 2013a, Conforti 2017). In Mongolia, recent analysis by Troubat and colleagues suggests that the HSES-HH's diary instrument could be satisfactorily substituted with a less costly consumption recall combined with measurement of changes in household foods stocks and acquisitions (Troubat 2017).

Per-capita estimates of household consumption density more closely agreed with dietary-derived per-capita intake densities in both household types, particularly in the case of nutrients. To some degree, this agreement may be inflated by shared systematic error in the reporting of foods in both the FCS-HH and FCS-24 (e.g. the fact that both rely on memory and self-report) as well as nutritional analysis (e.g. the fact that the same food composition data was used to analyze both datasets) (Willett 2013c). The observed agreement is nonetheless encouraging given that nutrient densities are meaningful nutrition indicators in and of themselves, and which provide a convenient way to compare individuals with different caloric intakes despite the aforementioned sources of error (both of which are non-differential) (Willett 2013a).

Aims 2 and 3: Comparison between disaggregated household consumption estimates and individual dietary intake measurements

Next, we evaluated the validity of the AME method to disaggregate household food and nutrient consumption based on household members' relative caloric requirements. The validity of this method has been evaluated in numerous surveys outside Mongolia. In studies of two household consumption and expenditure surveys in Uganda, the AME method provided reasonable estimates of dietary nutrient density, but more often underestimated dietary intake of potential fortification vehicles among women and children in comparison with results of a nested 24-hour recall, varyingly explained by the inability of each survey's household instrument to fully enumerate-foods consumed and the extent to which the intra-household distribution of staple foods in Uganda is disproportionate to the caloric requirements of household members (Dary 2012, Jariseta 2012). By contrast, analysis of 4,195 Bangladeshi households revealed the AME method to produce remarkably accurate disaggregated estimates of most nutrients' dietary intake in comparison with results of 24-hour recalls collected from the same study population, implying that consumption of most foods would likely be accurately disaggregated as well (Sununtnasak 2017). This finding was corroborated by a pooled analysis of 6 Bangladeshi surveys including 1,232 households, which found that in Bangladesh, more so than in most of the 13 other countries for whom similar pooled analyses were undertaken, intra-household distribution of consumed calories appears to be relatively proportional to intra-household distribution of caloric requirements (this is a necessary, though not sufficient prerequisite for intra-household distribution of foods and non-caloric nutrients in a manner proportional to caloric requirements, which is a cardinal assumption of the AME method) (Berti 2012).

In the present study, application of the AME method to the larger HSES-HH showed it to be generally more apt than the statistical method at estimating and ranking individuals' intakes of dietary components, but it also overestimated intake in both household surveys and produced extremely narrow standard errors. The latter may be attributed to the AME method's relatively deterministic manner of disaggregating consumption, which could be addressed by assigning more granular estimates of energy expenditure (or by deliberately assigning error to estimates, drawn from error observed in energy expenditure prediction models (FAO 2005)). On the other hand, a benefit of a deterministic approach is that it does not imply a sample size requirement to produce precise disaggregated estimates (unlike the statistical method). With regard to the comparative accuracy of the AME method, some investigators specifically suggest that its strength lies in estimating intake of those dietary components more correlated with energy (Coates 2017b, Engle-Stone 2014). Accordingly, in disaggregation of the HSES-HH, the AME method more accurately estimated individuals' intakes of animal fat/eggs/dairy products, baked and fried flour products, and flours/grains/noodles, which are the major staples of the Mongolian diet and which are relatively calorie-dense and nutrient sparse. To the extent that dietary intake of caloric energy, macronutrients, and staple foods (for example, fortifiable flour) are ubiquitous and subject to homeostatic regulation (Willett 2013d), predicting individuals' intakes of these dietary components should require a disaggregation method to be less discriminating of components of variation in intra-household food consumption which are attributable to prevailing social or cultural forces rather than biological ones. In such cases, it may be more reasonable to depend on the AME method than the statistical method, the latter of which may incur statistical error without a discernible benefit to accuracy. The AME method may also be extended to a more generalized concept of intra-household "equivalency scales" by weighting nutrient household consumption according to nutrient requirements other than that of energy (Coates 2017b). If household food consumption is reported inaccurately, however (as verified in the case of the FCS), the AME method will produce biased estimates regardless of dietary components' known associations with energy or other nutrients' intake or requirements.

Unlike the AME disaggregation method, the statistical method has not been previously validated. The plausibility of dietary intake estimates produced by the statistical method is generally supported in the literature by its apparent ability to predict natural variation in caloric intake with age – increasing intake during childhood, a spike in puberty, and a decrease later in life – rather than by comparison with actual consumption data for energy or other dietary components (which had not previously been studied) (Chesher 1997, 1998; Vasdekis 2000, 2001; Miquel 2001; Naska 2001b; De Agostini 2005; Allais 2009; Bonnet 2014). Despite this, an advantage of a more data-driven statistical method over that of the AME would be expected in the case of dietary components whose consumption is less correlated with energy requirements (e.g. most foods (Table S3.4)), and those which are less correlated by definition (all food group and nutrient intake densities). Accordingly, the statistical method more accurately assigned dietary intake of food groups and intake densities of both food groups and nutrients in disaggregating both household surveys.

An interesting aspect of the statistical method is that its inclusion of a model intercept accommodates the possibility that not all household food is consumed and thus ought to be disaggregated, which could be important if household consumption were measured in terms of proxies such as food expenditure, acquisitions, or stocks; this is suggested by Chesher in the method's initial application to food acquisitions among British households (Chesher 1997). In disaggregating surveys which explicitly measure household food consumption (such as those analyzed in this study), the intercept explicitly represents consumption unrelated to the number, age, or sex of individuals living in each household, which may be useful if it helps account for food which was reported to be consumed but which was in fact merely acquired, present in the house but not consumed, given to animals, wasted, or which spoiled. This usefulness is supported by the statistical method's comparative accuracy in disaggregating consumption in the FCS-HH (Aim 2) despite this survey's overestimation of per-capita dietary intake (Aim 1). The utility of the intercept in this regard requires that household consumption is over-reported in an additive rather than a multiplicative fashion, otherwise the differences between predicted intakes across age-sex groups will be inflated (as will the model intercept); we have affirmed this experimentally by applying the statistical method after adjusting household consumption using either a constant or a multiplier (not shown). Conversely, to the extent that household food consumption is multiplicatively underestimated, the intercept will be attenuated, as will the differences in predicted intake across age-sex groups. This may have been responsible for the statistical method's poor performance in disaggregation of the HSES-HH (which likely experienced multiplicative underreporting associated with the burden of the diary instrument), and why performance improved after removing the model intercept in applying the AME-like ("SD2") adjustment. Thus, while the statistical method depends less on assumptions of accurate reporting of household consumption per se than the AME method, it is nonetheless influenced by the nature of this inaccuracy.

The statistical method is potentially limited in ways that the AME method is not, stemming from its reliance on accurate and precise prediction of household food consumption (without which accurate or precise estimates of dietary intake among different age-sex groups may not be inferred). For example, zero-inflation in the distribution of household food consumption due to the presence of non-consumers over the reference period may produce poor model fit and inaccurate predictions (Table S3.2). In this study, our use of zero-inflated models implies that non-consuming households would in fact be consumers given a longer reference period, which is likely a reasonable assumption for most food groups and nutrients (except alcohol), but which may not be reasonable were smaller (less aggregated) food groups to be analyzed. In such cases, a two-part or “hurdle” model which deliberately distinguishes between processes of household consumption frequency and consumption magnitude may be more appropriate for modeling mean household consumption in the population. With regard to precision, while smoothing parameter estimates may be helpful for producing more realistic estimates, the degree of smoothing is a subjective choice which may obscure rather than expose true variation in predicted dietary intake with age, particularly if the imprecision in estimates is severe. In this study, model fit of statistical disaggregation models was generally poor (Table S3.6). Improving precision is challenged by the fact the inclusion of highly predictive variables - household energy intake or household size - e.g. changes the interpretation of parameter estimates such that they reflect effects on household composition rather than the addition of household members (partly defeating the purpose of using the statistical method over the AME method, the latter of which is necessarily dependent upon assumptions of intra-household distribution).

Aim 4: Direct prediction of dietary nutrient intake by individuals

Finally, we attempted to estimate individuals' dietary intakes and intake densities using a prediction model incorporating household food consumption and other data feasibly obtainable from a household survey, with relatively precise results. While examples of this approach are relatively sparse in the literature (e.g. Engle-Stone 2015), we derived what we consider to be acceptably precise predictions of dietary nutrient intake and intake densities. Given the predictors available for model selection, results were similar between models directly predicting nutrient intake densities vs. those based on separate prediction of nutrient and energy intake. Similar to the statistical disaggregation method, the prediction model does not require potentially inaccurate assumptions about the intra-household distribution of food consumption. Prediction further relaxes assumptions that reporting of household food consumption is systematically (as in the case of the AME method) or differentially (as in the case of the statistical method) unbiased with respect to dietary intakes of household members, and offers more flexibility with respect to potential effect modifiers or confounders. For example, we found in Aim 1 that bias in per-capita household consumption was differentially affected by household size. In Aims 2 and 3, we found that despite attempting to control for household educational attainment, family composition, outside food spending, consumption by impermanent members, and locality, a strong pattern of increasing estimated intake in advanced age was observed in both the AME and statistical disaggregation estimates for most foods and nutrients, contrary to that which we expected based on both dietary energy intake and predicted energy expenditure. This pattern may result from residual confounding by socioeconomic status and household size, in that wealthier Mongolian households generally consume more food, are smaller (increasing per-capita food consumption), and their members have longer life expectancies (Sonomtseren 2011); it is also possible that smaller (and younger) households underreported food consumption, according to the cognitive hypothesis discussed previously in Aim 1 (to some extent, increasing intake with age may also be real, given that the Mongolian population is still relatively young and older individuals are more metabolically active than their counterparts in other populations). In addition to more efficient control for confounding variables, prediction allows estimates to be produced across more granular strata of individuals, while the statistical method may only do so with difficulty (for example, by analyzing strata independently and reducing statistical power, or by introducing a potentially unwieldy number of interaction terms between age-sex groups and covariates of interest (Chesher 1997)).

Based on our prediction models, we suggest that household surveys would be well adapted to estimate dietary intake and intake densities by the addition of a rudimentary dietary assessment module. Predictive approaches have performed well in analysis of food frequency questionnaires (FFQs), the rationale being that such an approach acknowledges "the importance of a food item should reflect not only the nutrient content of the food, but also the validity of the responses to that particular item" (Willett 2013b). Existing platforms for conducting household surveys would well-suited for applying this method, given that they are prepared using large, nationally-representative sample frames and are collected periodically. The expense of a validation study (i.e. simultaneous collection of dietary intake data with which to build a model) should not be considered a limiting factor, as it will also produce useful consumption estimates that could otherwise have been collected in a separate dietary survey; even cursory qualitative information about individuals' diets can be useful for assessing food security or screening for chronic disease risk (e.g. , Rifas-Shiman 2001, Kennedy 2011). Still, some may question the purpose of adding dietary assessment of individuals to a household survey in lieu of conducting a more rigorous standalone dietary assessment. If resources are available to do so, measurements collected in such a survey would assuredly be more accurate than those obtained through prediction. If resources are not available, however, prediction may offer a reasonable compromise between an infeasible approach and no approach at all. Furthermore, while it is not unreasonable to append a qualitative or semiquantitative dietary assessment module to an HSES questionnaire, more involved dietary measurements (such as diet records or a 24HR) may diminish compliance and compromise accurate collection of other survey modules. For the purpose of prediction, the level of detail at which to collect individuals' dietary and eating behavior information – cursory qualitative, cursory semiquantitative, or detailed semiquantitative – should be carefully considered in the context of a given HCE platform, not all of which may be suited to accommodate a highly detailed questionnaire. This should not preclude consideration of a more detailed quantitative or semiquantitative food frequency questionnaires, however (the value of which could not be evaluated in this study given the use of the 24HR). If an FFQ were used, a predictive model framework in the context of HCE data may enhance the instrument's usefulness in collecting absolute intake, while in the case of a 24HR, it may increase the instrument's ability to assess long-term diet.

Strengths and limitations

By disaggregating two household surveys from the same national population using two different instruments for assessing household food consumption (a recall and a diary), this study was able to assess the reproducibility of disaggregated household consumption estimates and study differences in survey design. The size of the HSES-HH allowed for more statistically-powerful disaggregation, while the FCS-HH, although a smaller survey, was conducted in the same population as the dietary assessment and thus allowed for an inherently more direct and multi-faceted comparison. Comparability of the two household surveys was strengthened in that both were nationally-representative, seasonally-matched, and conducted within two years of one another. Analysis of both individual dietary intake and household food consumption incorporated local and empirical food yield, food composition, and physical activity, and incorporated empirical estimates of food eaten outside of the home, allowing for more a more rigorous validation.

An important limitation of this study is potential underreporting by the 24-hour recall. The extent to which this has affected the comparative validity of the AME and statistical disaggregation methods is expectedly mitigated inasmuch as this underreporting affected both household surveys in a similar fashion, the fact that all disaggregated household results were compared to the same dietary assessment, the fact that dietary underreporting should not necessarily be expected to differentially bias reported or predicted intake of a given food group or nutrient across different age and sex groups; in validating both per-capita estimates (Aim 1) and disaggregated estimates (Aims 2 and 3), underreporting was further mitigated by conducting energy-adjusted analysis (Willett 2013a). Second, while suitable for assessing mean dietary intake, a single 24HR does not provide estimates of usual intake. Adjustment for within-person variance using variance components from the same national population helped to account for this limitation in the case of nutrients, but not food groups. Third, while various factors were applied to render household food consumption measurements comparable with dietary intake, including consumption by impermanent household members, we were unable to account for guests and visitors who affect household food supplies but were not accounted for by the surveys analyzed. A final limitation of this study was the lack of information on individual dietary intake by children, or by any age groups in seasons other than summer, making it impossible to determine the validity of the method for children or in different seasons in Mongolia. Further research is warranted to address this.

Conclusion

We note that each of different estimation methods has its own strengths, weaknesses, and applications, and that their performance depends importantly on survey-specific factors which may vary widely both between and within countries. In light of these observations, we find it inappropriate to categorically recommend one method over another, or to recommend against estimation entirely to focus more on measuring diet directly (notwithstanding the importance of ongoing efforts to advance dietary data collection globally, which should continue to be supported). We also support continuing efforts to capture household food consumption more accurately. In order to render these data more useful for applications in nutrition, they should be collected in ways that facilitate accurate disaggregation (Fuwa 2010, Fielder 2013b, Coates 2017a), including collection of ancillary data on intra-household food distribution or diet from at least a subset of survey households (the latter of which is compatible with our recommendations regarding expanded use of prediction models). We suggest that it would be valuable to conduct similar prediction exercises in other countries, evaluating different types of household and individual assessment instruments.

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Appendix

Appendix A: Creation of food groups, age groups, and other derived variables

Due to differences in the descriptiveness and granularity with which household food consumption and individual dietary intake were assessed across the two household surveys and the 24HR, foods reported in the FCS-HH, nested FCS-24, and HSES-HH were condensed into 12 broad food groups to allow more interpretable comparisons across surveys. One of these food groups, "Miscellaneous foods", was fairly small and its composition differed markedly across datasets, and was therefore omitted from further analyses. To conserve statistical power in disaggregation analysis of the smaller FCS-HH, individuals in all three surveys were condensed into 10 age groups: 0-4, 5-9, 10-14, 15-19, 20-29, 30-39, 40-49, 50-59, 60-69, and 70+ years. For use in regression models, variables were created in the FCS-HH and HSES-HH to quantify each individual's total daily predicted caloric requirement, and each household's total daily predicted caloric requirement separately attributable to the person-time of permanent and impermanent members present in the household (impermanent members were defined as registered household members - distinguished from guests and visitors - who reported at least one day away from the household during the reference period). These caloric variables were created using information on household members' time spent away from home and equations for predicting individuals' basal metabolic rate and caloric requirement which incorporated age, sex, height, weight, and physical activity categories (Table S3.1) (Schofield 1985, FAO 2005). As information on physical activity was not available in the HSES-HH, trimmed mean values of physical activity levels were estimated for individuals of different strata defined by age, sex, and urban vs. rural locality in the FCS-HH and assigned to individuals in corresponding strata in the HSES-HH. A categorical variable was also created for the FCS-HH and HSES-HH to describe households' family composition, distinguishing households with one adult male only, one adult female only, multiple adults, multiple adults and one or more children, children only, and no permanent members.

Appendix B: Derivation and application of survey weights

The FCS-HH, nested FCS-24, and HSES-HH study populations differ between one another (and between the Mongolian national population) in their distributions of variables expected to influence or otherwise associate with household food consumption and individual dietary intake. Survey weights were applied to (1) allow better comparability between disaggregated household consumption estimates obtained from the FCS-HH and HSES-HH household surveys and individual dietary intake in the FCS-24 (Aims 2 and 3), (2) derive more nationally-representative ingredient cooking yield factors from the FCS-24 for calculation of household nutrient consumption in the FCS-HH and HSES-HH (Appendix D), and (3) derive more nationally-representative components of variance in dietary nutrient intake from repeated days of diet records with which to adjust the FCS-24 measurements (Appendix E). For these purposes, weights were calculated for the FCS-HH, nested FCS-24, pooled independent samples of the 2012 and 2014 survey waves of the HSES-HH, and the nationwide diet records using reference data on the distribution of households across 42 strata defined by urban vs. rural locality and national province in the national census of Mongolia (Sonomtseren 2011). Weights were generated using the national census rather than the FCS-HH as the reference population in order to provide more nationally-representative estimates, and replaced those previously generated for households and individuals in the FCS-HH and HSES-HH in order to maintain comparability both between analyses of households and individuals and between analyses of the FCS-HH, nested FCS-24, HSES-HH, and diet records.

Appendix C: Adjustment of household food consumption measurements

For each food within each food group, reported total household consumption (in the FCS-HH and HSES-HH) and individuals' dietary intake (in the FCS-24) in grams, kilograms, pieces, or liters over the reference period was converted to grams per day, using food densities and mass equivalents as necessary (FAO 2012). Daily masses consumed were adjusted as needed for refuse factors (Haytowitz 2011) and an estimated wastage and spoilage factor of 10% for all foods as recommended by the Ministry of

Agriculture, Fisheries, and Food (MAFF 1999). Because the household consumption data analyzed in this study (and those of most household surveys) only account for consumption of foods originating from home supplies, FCS-HH and HSES-HH household consumption measurements of each food group was adjusted in an attempt to account for foods originating from outside home, using factors estimated for each food group within each urban and rural area of each national province. These stratum-specific factors were calculated using information from the FCS-24, namely the source of each food consumed (home vs. away from home), by computing a stratum-specific trimmed mean of the fraction of each food group sourced from outside of home and adding this fraction to each household's consumption of the corresponding food group in the corresponding stratum (this may be considered a food group-specific version of one of two approaches suggested by Chesher in statistical disaggregation of household energy consumption (Chesher 1997)).

Appendix D: Calculation of dietary nutrient intake and total household nutrient consumption

Daily consumption of 27 nutrients was calculated for individuals participating in the FCS-24 using a purpose-built food composition table previously compiled for Mongolian children, which included analyses of a limited number of local food samples (Lander 2009). This table was updated with local data on recipes and dish yields (FAO 2013, Bromage 2017), incorporating international food composition data primarily from the U.S and Germany (Hartmann 2005, Haytowitz 2011) after adjustment for differences in moisture and fat content (FAO 2013) and application of nutrient retention factors (NDL 2007) as appropriate. These data were also updated with refuse factors for analysis of the FCS-24 (Haytowitz 2011). Calculation of total daily nutrient consumption by households in the FCS-HH and HSES-HH began with each household's total daily food consumption adjusted for refuse, waste and spoilage, and eating out, and was further adjusted for changes in ingredient mass which occur during cooking of household foods (this was necessary because consumption of household ingredients was reported in terms of raw masses which were not immediately comparable with those reported in the 24HR). To do this, each ingredient consumed in the FCS-24 was first coded with a yield factor specific to each combination of ingredient and the food item that it was found in; the majority of these factors were empirical dish yields derived using locally-collected recipes (Bromage 2017), supplemented as appropriate with ingredient cooking yields from the U.S. and Germany (Mathhews 1975, Bognár 2002, Showell 2012). A survey-weighted average yield for each ingredient across all instances of its consumption in the FCS-24 was then calculated and used to adjust consumption of corresponding ingredients in both household surveys. Household nutrient consumption was then computed using the same food composition data used for analysis of the FCS-24. Calculated dietary energy intake and household energy consumption, dietary intake and household consumption of food groups and nutrients were also expressed in "energy-adjusted" terms (per 100 kcal of intake or consumption, respectively) to produce "intake densities" and "consumption densities", respectively (Willett 2013a).

Appendix E: Adjustment of dietary nutrient intakes for within-person variance

Regardless of sample size, data from a single 24HR per person do not provide accurate estimates of between-person variation in long-term diet (IOM 2000). The true distribution of dietary nutrient intake in each of four strata defined by urban vs. rural area and sex was estimated by adjusting each individual's observed intake according to an empirical Bayesian method, by which an individual's long-term dietary intake is expressed as a weighted average of their observed estimate and the stratum mean, in which the weights are strata-specific ratios of within- to between- person components of variance (Rosner 1983) (this method is comparable to the National Research Council method; IOM 2000). For this purpose, stratum- and nutrient-specific variance components were first estimated by analyzing nutrient intake data on 6 days of weighed diet records (3 in summer and 3 in winter) collected from 80 healthy Mongolian adults in each of four strata defined by urban vs. rural locality and sex (Bromage 2017), using a survey-weighted fixed effects model in which the logarithm of daily nutrient intake was regressed upon the variables participant ID, season, and day type (weekday vs. weekend day) (SAS v9.4 'glm' procedure). Five of 1,839 available person-days of observation for which the ratio of daily total energy intake (TEI) to daily total energy expenditure (TEE) lay beyond 3 standard deviations of the grand (all-strata) median were excluded prior to partitioning variance following a comparable approach in the literature (e.g. Mulligan 2014), followed by exclusion of 4 person-days of similarly extreme dietary intake (> or <3SD) of each nutrient being considered. Estimated ratios of within- to between-person variance for each nutrient and stratum are given in Table S3.2.

Differences in the ways that foods and ingredients were expressed in the FCS-24 and diet records prohibited this variance adjustment for food groups. Statistics which rely on accurate estimates of between-person variation in individuals' dietary intakes (namely, coverage probability of disaggregated household consumption estimates (Aims 2 and 3) and mean absolute bias and percentage of deviance explained in prediction of individual dietary intakes and intake densities (Aim 4)) are therefore estimated exclusively for nutrients. Furthermore, given the lack of repeated measures data for household nutrient consumption, observed household consumption of both food groups and nutrients is similarly unadjusted for within-household variance. However, resulting imprecision is expectedly mitigated by the fact that these household consumption estimates are in fact averages of 7, 10, or 30 day-long reference periods (the relative stability of household estimates is partly supported by the higher observed correlations between household consumption of different foods, particularly nutrients (Table S3.4)).

Appendix F: Equations for describing the statistical and AME disaggregation methods

Statistical method:

Let HC_i = total household consumption of a food group or nutrient.

X_{ij} = the number of persons in the jth age-sex group within the ith household ($j = 1,\dots,20$).

Z_i = a vector of covariates (education, family composition, locality, outside food consumption, caloric contribution of impermanent members).

I = 1,012 or 9,424 households in the FCS-HH and HSES-HH, respectively.

Regression was run of the following form using a Tweedie error distribution, identity link function, and one of 21 possible values of the Tweedie index parameter *p* (ranging from 1 to 3 in increments of 0.1) which produced the smallest ratio of residual to null deviance:

$$Eq.1: HC_i = \alpha + \sum_{j=1}^{20} \beta_j X_{ij} + \sum_{k=1}^{5} \gamma_k Z_{ik} \ , i = 1, \dots, l$$

In the unadjusted statistical method ("SD1"), individuals' dietary intakes $y_{i,\ SD1}$ were set to their age- and sex-specific parameter estimate (the latter of which were first smoothed across age groups within each sex using regression splines):

$$Eq.2: y_{i,\ SD1} = \beta_i$$

In the alternate "AME-like" statistical method ("SD2"), individuals' dietary intakes were instead calculated as follows:

Let $y_{ij,\ SD2}$ = dietary intake of individuals in the jth age-sex group and ith household.

$$Eq.3: y_{ij,\ SD2} = HC_i * \beta_{im} / \sum_{m=1}^{n_i} \beta_{im} \, , j = 1, \dots, n_i$$

AME method:

Let HC_i = total household consumption of a food group or nutrient (adjusted for education, family composition, locality, outside food consumption, and caloric contribution of impermanent members using the residual method).

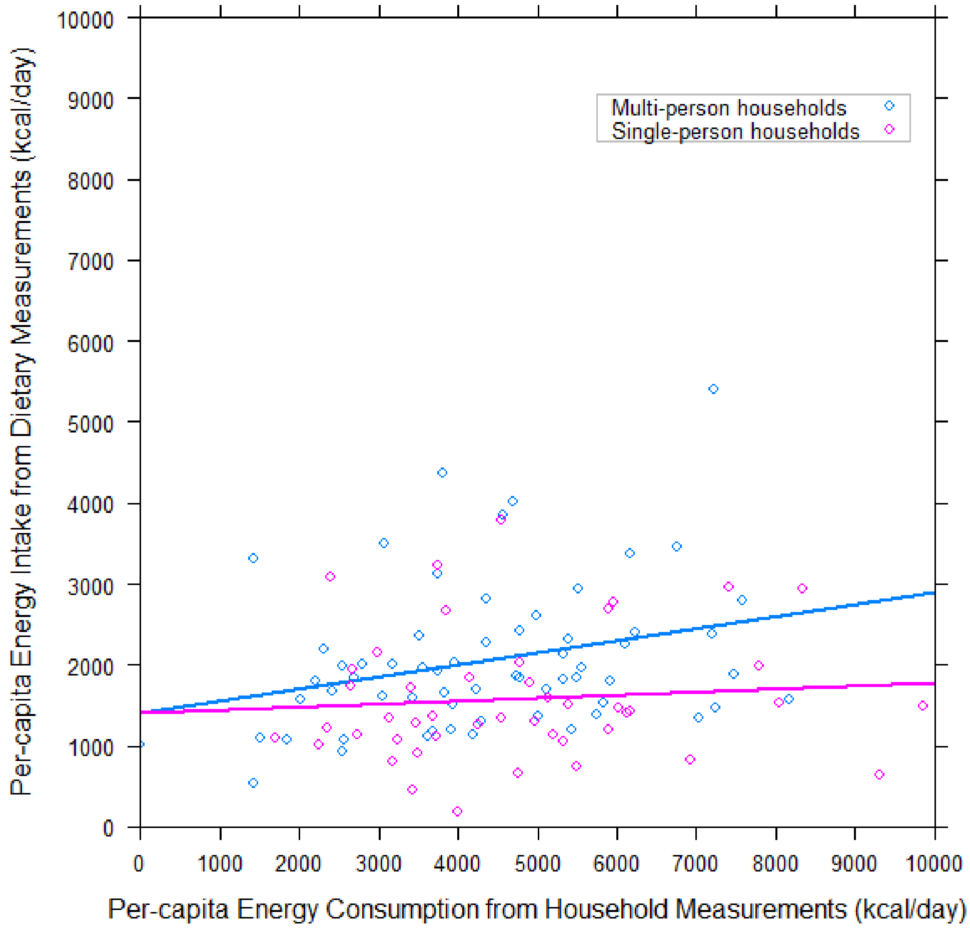
C_{im} = caloric requirement for the mth person in the ith household (Table S3.1).

$y_{ij,\ AME}$ = dietary intake of individuals in the jth age-sex group and ith household.

Individuals' dietary intakes were calculated as follows:

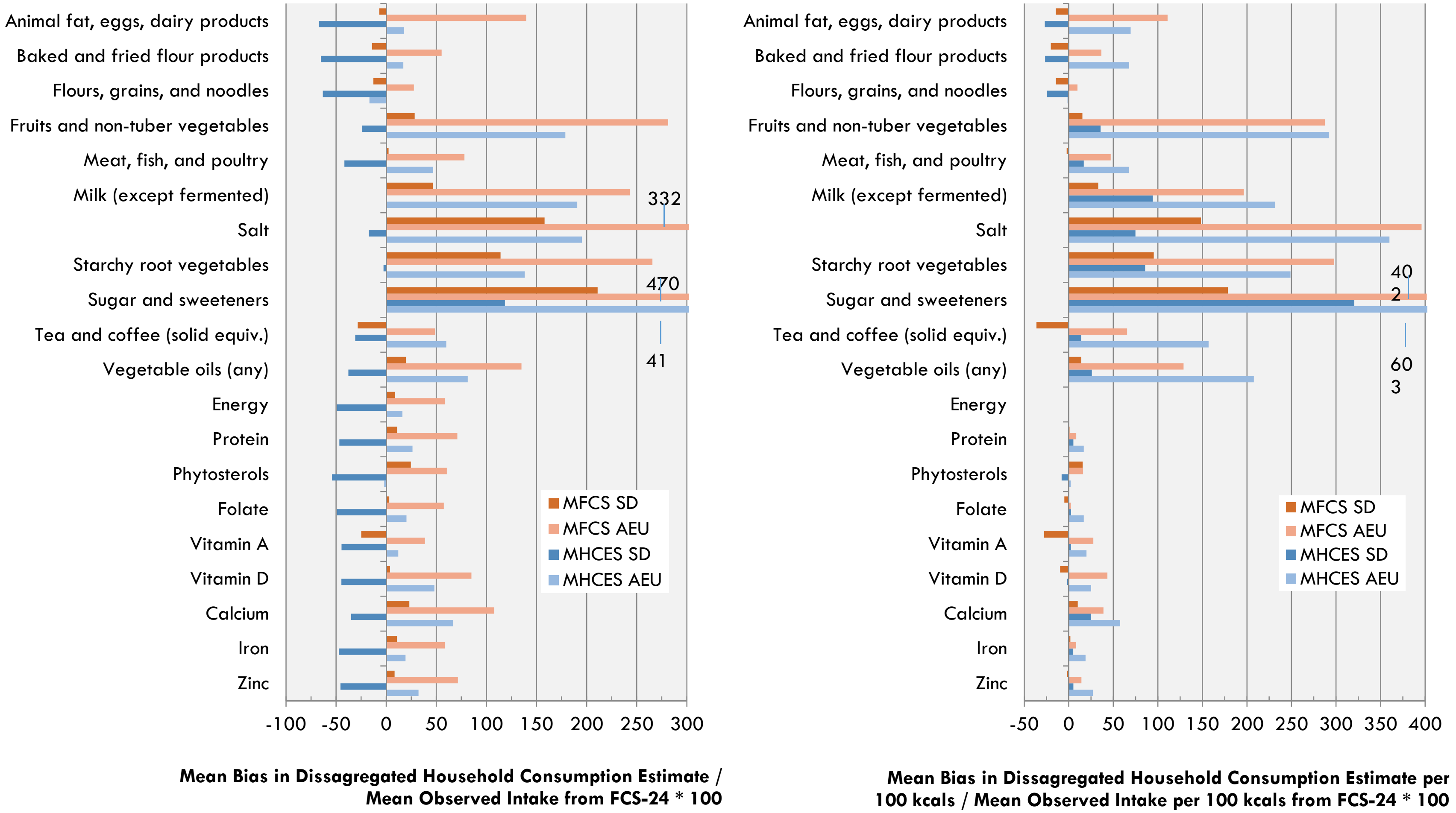
$$Eq. 5: y_{ij,\ AME} = \mathrm{HC_i} * \ \mathrm{C_{im}} / \sum_{\mathrm{m=1}}^{\mathrm{n_i}} \mathrm{C_{im}}\, , j = 1, \dots , \mathrm{n_i}$$

Figure S3.1: Relationship between per-capita household energy consumption and per-capita dietary intake (kcal/day) among 109 FCS-HH households fully-enumerated by the nested FCS-24 (Aim 1)



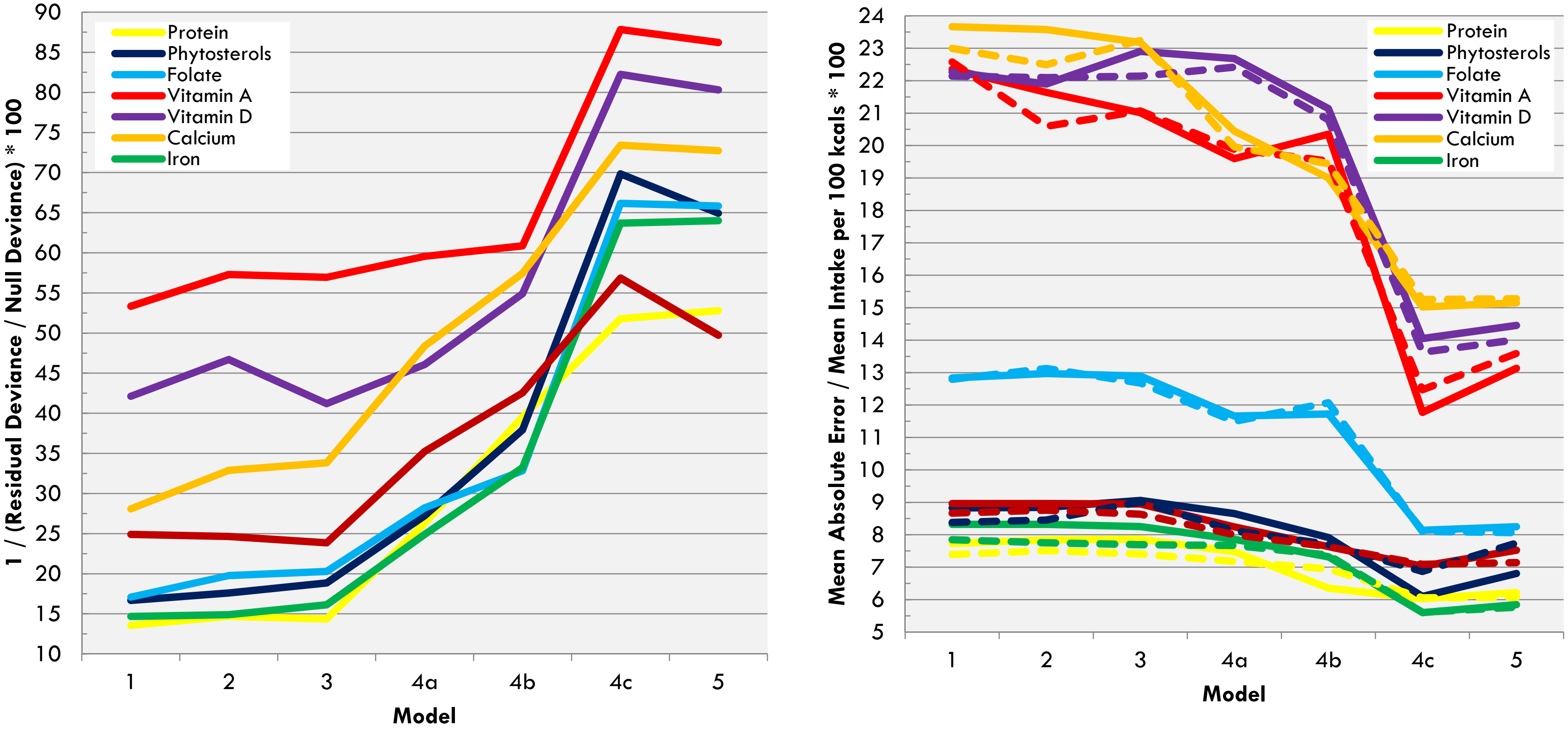
Pearson correlation coefficients for multi- and single-person households: 0.29 and 0.09, respectively (Spearman rank correlation coefficients: 0.29 and 0.14, respectively).

Figure S3.2: Mean bias of disaggregated household consumption estimates of individuals' food group and selected nutrient intake and intake density (per 100 kcal) across 14 age-sex groups (Aims 2 and 3)



Values for 5 data points exceed the graphs' x-axis limits and are indicated using annotations. Abbreviations: FCS-HH (2013 Food Consumption Survey), FCS-24 (nested 24-hour recall), HSES-HH (2012/2014 Household Socio-Economic Survey), SD1 (unadjusted statistical disaggregation method), AME (adult male equivalent method). Statistics are survey weighted.

Figure S3.3: In-sample fit statistics for increasingly complex predictive models of individuals' dietary intakes densities of selected nutrients in the FCS-24 (Aim 4)



In the right panel, dashed lines indicate mean absolute error estimated by separately predicting nutrient intake and energy intake, dividing predicted nutrient intake by predicted energy intake, and comparing the results to observed dietary intake measurements in the FCS-24, while solid lines indicate mean absolute error of predicting nutrient intake densities directly. See Table 3.4 for detailed descriptions of models 1-5. Brief description of variable categories considered for selection in each model: (1) Household and individual demographic, socioeconomic, and lifestyle characteristics, (2) Model 1 variables + quantitative total household consumption of food groups and nutrients, (3) Model 2 variables + individuals' self-evaluation of nutrition knowledge and its application to their lives, (4a) Model 3 variables + cursory qualitative 24-hour recall and assessment of eating behaviors, (4b) Model 3 variables + cursory semiquantitative 24-hour recall and assessment of eating behaviors, (4c) Model 3 variables + detailed semiquantitative 24-hour recall, (5) Model 4 variables + measured anthropometry. Abbreviation: FCS-24 (nested 24-hour recall of the 2013 Food Consumption Survey).

Table S3.1: Schofield equations for predicting individuals' basal metabolic rate

Sex	Age	Equation
Male	0-3 yrs	0.0007 * W + 6.349 * H - 2.584
	3-10 yrs	0.082 * W + 0.545 * H + 1.736
	10-18 yrs	0.068 * W + 0.574 * H + 2.157
	18-30 yrs	0.063 * W - 0.042 * H + 2.953
	30-60 yrs	0.048 * W - 0.011 * H + 3.670
	60+ yrs	0.038 * W + 4.068 * H - 3.491
Female	0-3 yrs	0.068 * W + 4.281 * H - 1.730
	3-10 yrs	0.071 * W + 0.677 * H + 1.553
	10-18 yrs	0.035 * W + 1.948 * H + 0.837
	18-30 yrs	0.057 * W + 1.184 * H + 0.411
	30-60 yrs	0.034 * W + 0.006 * H + 3.50
	60+ yrs	0.033 * W + 1.917 * H - 0.074

Table is reproduced from Schofield 1985. Total energy expenditure is estimated by multiplying basal metabolic rate by the mean of a range of coefficients suggested for different categories of physical activity level: sedentary or light activity (1.40-1.69), active or moderately active (1.70-1.99), vigorous or vigorously active (2.00-2.40) (FAO 2005).

Table S3.2: Ratios of within- to between-person components of variance in dietary nutrient intakes within subgroups of men and women in urban and rural Mongolia

	Area:	**Rural**		**Urban**	
	Sex:	**Female**	**Male**	**Female**	**Male**
Macronutrients	Energy	2.1	2.5	1.2	2.9
	Carbohydrates	2.7	1.7	1.0	3.1
	Protein	1.8	3.2	2.1	3.5
	Total fat	1.9	2.1	1.5	2.9
	Alcohol	3.3	1.5	7.9	3.5
	Water	1.2	0.9	1.0	1.2
	Fiber	2.9	2.5	1.5	3.6
	Phytosterols	3.8	3.3	1.7	4.4
Vitamins	Thiamin	2.3	1.6	1.5	2.3
	Riboflavin	1.6	1.8	1.9	3.2
	Niacin	3.6	4.0	2.7	2.5
	Pantothenic acid	1.5	2.4	1.8	4.4
	Vitamin B6	1.6	1.3	2.7	2.9
	Folate	1.7	1.2	1.6	2.3
	Vitamin B12	4.9	3.5	7.0	4.1
	Vitamin C	4.1	20.9	8.5	5.3
	Vitamin A	2.2	2.8	4.2	3.8
	Vitamin D	1.8	1.7	2.9	6.5
	Vitamin E	2.9	1.8	1.8	9.0
Minerals	Calcium	1.0	0.9	1.6	1.8
	Copper	2.1	2.8	2.6	3.7
	Iron	2.3	1.7	1.8	3.0
	Magnesium	1.5	2.1	1.7	3.2
	Manganese	1.6	2.3	1.3	3.7
	Phosphorus	2.0	1.9	1.5	2.9
	Potassium	1.6	2.5	2.3	3.9
	Zinc	2.5	6.0	3.1	3.3

Components of variance are derived from analysis of 3-day summer and winter diet records collected from 320 Mongolian adults living in urban and rural Mongolia, and are survey-weighted.

Table S3.3: Percentage of individuals or households observed to consume any of each food group or nutrient during each survey's reference period

	Survey:	FCS-24	FCS-HH	HSES-HH
	n:	1368 individuals	1017 households	9849 households
	Length of Reference Period:	1 day	7 to 30 days	7 to 10 days
Food Groups	Animal fat, eggs, and dairy products	53.5	95.6	87.8
	Baked and fried flour products	83.3	94.6	85.1
	Flours, grains, and noodles	94.6	100.0	99.8
	Fruits and non-tuber vegetables	62.6	95.6	90.0
	Meat, fish, and poultry	97.1	99.5	99.9
	Milk (except fermented)	71.6	95.4	94.1
	Salt	82.3	98.0	98.6
	Starchy root vegetables	53.8	93.2	82.5
	Sugar and sweeteners	20.1	98.6	98.4
	Tea or coffee (solid equivalent)	49.3	92.5	96.7
	Vegetable oils (any)	41.4	95.6	82.5
Macronutrients	Energy	100.0	100.0	100.0
	Carbohydrates	100.0	100.0	100.0
	Protein	100.0	100.0	100.0
	Total fat	100.0	100.0	100.0
	Alcohol	3.5	20.0	11.3
	Water	100.0	100.0	100.0
	Fiber	99.9	100.0	100.0
	Phytosterols	99.8	100.0	100.0
Vitamins	Thiamin	100.0	100.0	100.0
	Riboflavin	100.0	100.0	100.0
	Niacin	100.0	100.0	100.0
	Pantothenic acid	100.0	100.0	100.0
	Vitamin B6	100.0	100.0	100.0
	Folate	100.0	100.0	100.0
	Vitamin B12	99.9	99.9	100.0
	Vitamin C	96.8	99.9	99.8
	Vitamin A	96.9	99.7	99.4
	Vitamin D	93.8	99.3	99.1
	Vitamin E	100.0	100.0	100.0
Minerals	Calcium	100.0	100.0	100.0
	Copper	100.0	100.0	100.0
	Iron	100.0	100.0	100.0
	Magnesium	100.0	100.0	100.0
	Manganese	100.0	100.0	100.0
	Phosphorus	100.0	100.0	100.0
	Potassium	100.0	100.0	100.0
	Zinc	100.0	100.0	100.0

Statistics are derived after restricting HSES-HH data to those collected in May, June, July, or August, and prior to excluding households with no permanent members or individuals with ratios of total energy intake to expenditure lying 3 standard deviations beyond the median. Shading indicates values less than 100%. Abbreviations: FCS-HH (2013 Food Consumption Survey); FCS-24 (nested 24-hour recall), HSES-HH (2012/2014 Household Socio-Economic Survey.

Table S3.4: Correlations between food groups and selected nutrients ' total daily household consumption in the FCS-HH (upper) and individuals' daily dietary intake in the FCS-24 (lower)

Animal fat, eggs, dairy	Baked and fried flour	Flours, grains, and noodles	Fruits and non-tuber vegetables	Meat, fish, and poultry	Milk (except fermented)	Salt	Starchy root vegetables	Sugar and sweeteners	Tea and coffee (solid equiv.)	Vegetable oils (any)	Energy	Protein	Folate	Phytosterols	Vitamin A	Vitamin D	Calcium	Iron	Zinc	
1.00	0.21	0.31	0.01	0.30	0.51	0.20	-0.00	0.35	0.12	0.10	0.58	0.60	0.46	0.26	0.51	0.51	0.79	0.35	0.56	Animal fat, eggs, dairy products
	1.00	0.28	0.25	0.31	0.17	0.15	0.15	0.30	0.20	0.14	0.64	0.49	0.80	0.50	0.31	0.35	0.37	0.78	0.44	Baked and fried flour products
		1.00	0.09	0.31	0.22	0.30	0.19	0.44	0.24	0.27	0.73	0.61	0.60	0.80	0.34	0.26	0.33	0.61	0.53	Flours, grains, and noodles
			1.00	0.32	0.01	-0.05	0.26	0.01	0.07	0.23	0.25	0.26	0.31	0.29	0.35	0.34	0.11	0.34	0.23	Fruits and non-tuber vegetables
				1.00	0.23	0.16	0.17	0.30	0.15	0.20	0.65	0.81	0.54	0.41	0.51	0.50	0.37	0.72	0.89	Meat, fish, and poultry
					1.00	0.15	0.02	0.29	0.17	0.12	0.51	0.54	0.34	0.20	0.43	0.58	0.89	0.31	0.49	Milk (except fermented)
						1.00	0.18	0.32	0.20	0.25	0.34	0.27	0.28	0.26	0.22	0.19	0.21	0.27	0.25	Salt
							1.00	0.09	0.05	0.33	0.25	0.20	0.22	0.34	0.21	0.12	0.08	0.27	0.17	Starchy root vegetables
								1.00	0.42	0.17	0.56	0.48	0.49	0.40	0.34	0.29	0.38	0.45	0.45	Sugar and sweeteners
									1.00	0.07	0.31	0.26	0.36	0.26	0.22	0.17	0.18	0.27	0.24	Tea and coffee (solid equiv.)
										1.00	0.33	0.24	0.23	0.28	0.22	0.21	0.18	0.29	0.22	Vegetable oils (any)
											1.00	0.93	0.89	0.75	0.63	0.65	0.69	0.90	0.88	Energy
												1.00	0.78	0.64	0.65	0.68	0.72	0.85	0.96	Protein
													1.00	0.71	0.52	0.51	0.54	0.89	0.73	Folate
														1.00	0.41	0.39	0.34	0.72	0.57	Phytosterols
															1.00	0.58	0.56	0.54	0.59	Vitamin A
																1.00	0.66	0.52	0.63	Vitamin D
																	1.00	0.52	0.65	Calcium
																		1.00	0.82	Iron
																			1.00	Zinc
1.00	0.05	-0.01	0.01	-0.01	0.08	0.00	-0.03	0.17	-0.05	0.01	0.17	0.17	0.18	0.02	0.01	0.06	0.60	0.03	0.10	Animal fat, eggs, dairy products
	1.00	-0.09	-0.05	-0.11	0.05	0.03	-0.04	0.08	-0.02	-0.08	0.34	0.08	0.59	0.16	-0.03	0.12	0.19	0.35	0.01	Baked and fried flour products
		1.00	0.03	0.36	-0.01	0.08	0.26	-0.05	0.05	0.42	0.56	0.49	0.29	0.64	0.11	0.02	0.05	0.41	0.46	Flours, grains, and noodles
			1.00	0.07	-0.04	0.08	0.08	-0.01	0.08	0.09	0.00	-0.01	-0.04	-0.05	0.04	0.05	-0.00	-0.01	0.01	Fruits and non-tuber vegetables
				1.00	-0.02	0.04	0.24	-0.06	0.05	0.15	0.46	0.68	0.26	0.27	0.38	0.19	0.03	0.65	0.72	Meat, fish, and poultry
					1.00	0.08	-0.07	0.08	-0.01	-0.04	0.14	0.12	0.11	0.06	-0.02	0.12	0.53	0.04	0.06	Milk (except fermented)
						1.00	0.02	-0.02	0.03	0.10	0.08	0.05	0.08	0.05	0.02	-0.00	0.05	0.07	0.05	Salt
							1.00	-0.08	0.08	0.21	0.14	0.14	0.03	0.14	0.00	0.04	-0.05	0.12	0.17	Starchy root vegetables
								1.00	-0.01	-0.05	0.06	0.01	0.05	0.00	-0.01	0.01	0.15	0.02	0.01	Sugar and sweeteners
									1.00	0.02	0.00	-0.01	-0.01	-0.00	0.04	0.09	-0.05	0.01	0.01	Tea and coffee (solid equiv.)
										1.00	0.27	0.19	0.07	0.19	0.01	0.01	-0.01	0.16	0.16	Vegetable oils (any)
											1.00	0.87	0.76	0.76	0.18	0.11	0.36	0.84	0.79	Energy
												1.00	0.60	0.65	0.32	0.16	0.35	0.85	0.93	Protein
													1.00	0.57	0.23	0.03	0.32	0.76	0.54	Folate
														1.00	0.11	0.02	0.17	0.62	0.62	Phytosterols
															1.00	0.19	-0.01	0.42	0.43	Vitamin A
																1.00	0.12	0.17	0.13	Vitamin D
																	1.00	0.22	0.19	Calcium
																		1.00	0.83	Iron
																			1.00	Zinc

Green-Yellow-Red shading indicates the magnitude of absolute correlation (Green: minimum observed absolute correlation; Yellow: median; Green: maximum). Abbreviations: FCS-HH (2013 Food Consumption Survey); FCS-24 (nested 24-hour recall).

Table S3.5: Mean per-capita dietary intakes and intake densities (per 100 kcal), household consumption and consumption densities (per 100 kcal), and correlation between dietary-derived and household-derived per-capita measurements among 109 FCS-HH households fully-enumerated in the nested FCS-24 (Aim 1)

	Statistic:	**Mean Per-capita Intake or Consumption**								**Mean Per-capita Intake or Consumption Density (per 100 kcal)**							
	Household Type:	**Multi-person (n=63)**				**Single-person (n=46)**				**Multi-person (n=63)**				**Single-person (n=46)**			
	Derivation of Statistic:	**Diet**	**HH**	r_p	r_s	**Diet**	**HH**	r_p	r_s	**Diet**	**HH**	r_p	r_s	**Diet**	**HH**	r_p	r_s
Food Groups	Animal fat, eggs, dairy products (g)	111.9	343.4	0.17	0.35	61.1	231.8	0.37	0.41	5.30	7.35	0.14	0.37	4.05	5.31	0.49	0.32
	Baked and fried flour products (g)	112.5	206.4	0.03	0.07	87.2	219.9	0.25	0.13	5.86	4.50	-0.10	-0.02	5.98	4.66	0.25	0.15
	Flours, grains, and noodles (g)	243.4	409.4	0.02	-0.02	221.7	433.9	0.19	0.19	12.44	9.63	0.12	0.07	14.18	9.38	0.06	0.16
	Fruits and non-tuber vegetables (g)	27.8	124.7	0.50	0.59	20.6	162.4	0.16	0.16	1.39	3.09	0.35	0.61	1.28	3.39	0.15	0.10
	Meat, fish, and poultry (g)	103.3	311.5	0.05	0.19	106.3	433.9	0.25	0.09	5.24	7.11	0.14	0.13	6.83	8.76	0.04	-0.08
	Milk (except fermented) (g)	100.7	447.9	0.16	0.35	78.1	549.5	0.03	0.13	5.23	9.89	0.16	0.26	6.09	11.84	0.24	0.30
	Salt (g)	3.0	10.3	-0.03	0.15	1.6	11.1	0.01	-0.11	0.18	0.26	-0.09	0.24	0.12	0.28	0.38	0.22
	Starchy root vegetables (g)	20.3	110.3	0.12	0.15	25.9	172.2	0.14	0.26	1.04	2.62	-0.02	0.05	1.89	3.68	0.28	0.23
	Sugar and sweeteners (g)	5.4	29.9	0.17	0.20	5.1	23.3	0.28	0.49	0.30	0.67	0.17	0.08	0.43	0.55	0.13	0.40
	Tea and coffee (solid equiv.) (g)	2.6	7.3	0.08	0.00	2.2	8.1	0.10	-0.01	0.16	0.18	0.12	0.07	0.17	0.20	0.29	-0.02
	Vegetable oils (any) (g)	6.7	18.2	0.13	0.05	6.9	27.4	0.16	0.00	0.33	0.45	0.20	0.16	0.45	0.64	0.14	0.00
Macronutrients	Energy (kcal)	2070	4438	0.29	0.29	1583	4767	0.09	0.14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Carbohydrates (g)	262.49	518.88	0.15	0.21	205.51	548.69	0.09	0.09	12.844	11.883	0.08	0.19	13.113	11.682	-0.11	-0.13
	Protein (g)	74.28	189.21	0.28	0.36	60.22	218.59	0.20	0.14	3.633	4.265	0.33	0.32	3.806	4.488	0.08	-0.04
	Total fat (g)	72.54	174.90	0.28	0.37	55.89	186.46	0.01	0.09	3.527	3.857	0.01	0.06	3.505	3.876	-0.11	-0.04
	Alcohol (g)	8.30	1.06	0.64	0.47	0.85	0.89	0.80	0.47	0.258	0.021	0.44	0.47	0.028	0.030	0.89	0.47
	Water (g)	567.40	1785.34	0.25	0.30	473.91	2114.16	-0.03	-0.02	29.664	40.752	0.10	0.09	32.100	46.582	0.17	0.09
	Fiber (g)	9.3	19.2	0.16	0.24	7.1	21.8	0.18	0.10	0.45	0.45	0.22	0.27	0.44	0.45	0.04	-0.04
	Phytosterols (mg)	434	917	-0.06	-0.04	392	1082	0.11	0.11	21.8	21.4	0.20	0.07	24.7	23.2	-0.10	-0.05
Vitamins	Thiamin (mg)	0.780	1.831	0.16	0.15	0.653	2.288	0.25	0.11	0.0396	0.0418	0.08	0.06	0.0432	0.0482	0.10	0.12
	Riboflavin (mg)	1.143	3.557	0.19	0.25	1.012	4.247	0.23	0.05	0.0586	0.0800	0.09	0.13	0.0686	0.0901	0.07	0.16
	Niacin (mg)	12.498	32.558	0.17	0.25	11.479	42.713	0.28	0.24	0.6351	0.7379	0.27	0.28	0.7372	0.8635	0.06	-0.07
	Pantothenic acid (mg)	3.145	8.502	0.31	0.34	2.683	9.943	0.25	0.03	0.1582	0.1942	0.21	0.14	0.1747	0.2107	0.15	0.25
	Vitamin B6 (mg)	0.579	1.565	0.34	0.36	0.514	1.931	0.17	0.18	0.0300	0.0370	0.37	0.44	0.0325	0.0413	0.13	0.23
	Folate (µg)	141	307	0.20	0.26	100	302	0.04	0.00	7.0	6.8	0.13	0.11	6.3	6.4	0.16	0.21
	Vitamin B12 (µg)	4.48	13.69	0.16	0.25	5.24	13.29	0.37	-0.05	0.234	0.317	0.10	0.11	0.335	0.274	0.11	-0.13
	Vitamin C (mg)	8.0	35.8	0.36	0.29	7.6	43.6	0.18	0.26	0.41	0.83	0.20	0.10	0.48	0.91	0.04	0.09
	Vitamin A (µg)	330	900	0.12	0.14	289	728	0.10	0.16	17.0	21.2	-0.08	-0.06	19.4	16.3	-0.06	0.16
	Vitamin D (IU)	26	61	0.27	0.41	40	73	0.35	0.12	1.4	1.3	0.34	0.41	1.8	1.5	0.24	0.10
	Vitamin E (mg)	5.38	12.92	0.17	0.18	4.74	16.85	0.05	-0.09	0.268	0.301	0.20	0.16	0.286	0.377	-0.01	-0.10
Minerals	Calcium (mg)	460	1449	0.26	0.33	338	1615	0.10	0.13	23.2	32.3	0.15	0.28	24.0	35.2	0.29	0.26
	Copper (mg)	0.809	2.097	0.18	0.18	0.827	2.560	0.41	0.27	0.0414	0.0487	0.06	0.10	0.0538	0.0535	0.10	0.27
	Iron (mg)	9.85	22.80	0.20	0.24	8.56	27.44	0.31	0.17	0.498	0.522	0.22	0.22	0.545	0.564	0.07	0.04
	Magnesium (mg)	176	421	0.25	0.23	144	471	0.06	0.01	8.6	9.8	0.45	0.38	8.9	10.0	-0.02	0.02
	Manganese (mg)	2.257	4.791	0.11	0.15	1.797	5.285	0.15	0.10	0.1150	0.1125	0.39	0.37	0.1158	0.1140	0.00	0.25
	Phosphorus (mg)	971	2512	0.27	0.27	750	2857	0.06	-0.03	48.2	56.0	0.20	0.30	48.7	60.0	0.16	0.19
	Potassium (mg)	1405	3997	0.28	0.32	1214	5072	0.04	0.01	69.3	92.1	0.30	0.33	77.3	107.1	0.15	0.13
	Zinc (mg)	10.49	29.84	0.13	0.27	9.77	38.27	0.19	0.16	0.514	0.672	0.19	0.22	0.617	0.777	0.09	-0.05

Table S3.5 (continued)

Mean per-capita dietary-derived estimates and mean per-capita household-derived estimates are given in the "Diet" and "HH" columns, respectively. Green-Yellow-Red shading indicates the magnitude of absolute percent difference between household consumption and dietary intake (Green: minimum observed absolute percent difference; Yellow: median; Green: maximum), and Blue-Yellow-Red shading indicates the magnitude of absolute percent difference between household consumption density and dietary intake density (per 100 kcal) (Blue: minimum observed absolute percent difference; Yellow: median; Red: maximum). Abbreviations: FCS-HH (2013 Food Consumption Survey), FCS-24 (nested 24-hour recall), r_p (Pearson correlation coefficient), r_s (Spearman rank correlation coefficient), IU (international unit; 40 IU = 1 µg).

Table S3.6: Goodness of fit statistics for statistical disaggregation models of household food group and nutrient consumption

	Household Survey:	FCS-HH			HSES-HH		
	Statistic:	% Deviance Explained	MAE	(Mean HH Consumption)	% Deviance Explained	MAE	(Mean HH Consumption)
Food Groups	Animal fat, eggs, and dairy products (g)	24.8	552.0	687.2	23.1	259.4	303.5
	Baked and fried flour products (g)	12.8	322.3	578.2	19.3	202.2	401.2
	Flours, grains, and noodles (g)	33.9	352.9	1070.6	51.1	251.1	635.2
	Fruits and non-tuber vegetables (g)	25.2	218.1	375.6	12.0	161.7	235.0
	Meat, fish, and poultry (g)	14.2	309.6	679.8	27.2	231.7	531.4
	Milk (except fermented) (g)	28.2	553.9	843.5	34.3	446.0	671.4
	Salt (g)	16.7	12.7	26.6	12.9	7.6	17.3
	Starchy root vegetables (g)	15.3	212.2	365.6	11.3	129.1	206.4
	Sugar and sweeteners (g)	24.5	35.8	67.7	17.9	32.5	53.8
	Tea or coffee (solid equivalent) (g)	9.5	9.7	14.3	10.2	9.5	14.5
	Vegetable oils (any) (g)	13.5	25.9	52.3	7.6	21.4	32.4
Macronutrients	Energy (kcal)	35.0	3269	10765	34.1	2418	7191
	Carbohydrates (g)	39.5	386.22	1343.84	42.2	278.32	858.80
	Protein (g)	27.8	147.23	432.05	41.7	105.00	293.08
	Total fat (g)	24.4	156.74	400.55	19.4	120.67	284.42
	Alcohol (g)	10.5	4.42	2.78	2.0	5.32	2.91
	Water (g)	24.2	1480.79	4013.84	33.9	1159.92	2900.21
	Fiber (g)	33.4	15.8	52.6	32.8	10.9	33.0
	Phytosterols (mg)	28.7	849	2464	37.8	488	1394
Vitamins	Thiamin (mg)	26.8	1.619	4.844	23.2	1.195	3.472
	Riboflavin (mg)	24.9	3.059	7.803	33.8	2.132	5.493
	Niacin (mg)	23.8	27.576	79.791	28.1	19.840	56.814
	Pantothenic acid (mg)	26.7	6.743	20.356	35.9	5.004	14.181
	Vitamin B6 (mg)	27.8	1.420	4.144	24.7	0.957	2.603
	Folate (μg)	27.2	269	751	28.4	174	528
	Vitamin B12 (μg)	16.1	14.04	27.44	26.4	10.87	20.95
	Vitamin C (mg)	23.4	56.5	110.5	13.3	40.9	74.3
	Vitamin A (μg)	13.8	1145	2027	12.9	923	1411
	Vitamin D (IU)	15.1	83	154	11.5	68	110
	Vitamin E (mg)	21.3	12.43	34.35	13.7	10.14	21.53
Minerals	Calcium (mg)	23.2	1492	3105	31.1	1111	2262
	Copper (mg)	30.5	1.691	5.292	32.7	1.315	3.584
	Iron (mg)	29.6	17.89	57.26	28.4	12.86	39.53
	Magnesium (mg)	31.6	305	1028	38.1	233	688
	Manganese (mg)	36.6	3.519	12.357	40.4	2.655	8.617
	Phosphorus (mg)	30.6	1955	5677	38.8	1313	3724
	Potassium (mg)	24.5	3182	9506	34.1	2382	6601
	Zinc (mg)	25.5	24.32	66.27	39.0	17.68	47.21

Table S3.6 (continued)

% Deviance Explained = (1 - Residual Deviance / Null Deviance) * 100. $p<0.001$ for Chi-square residual deviance tests of goodness of fit for all food groups and nutrients. Mean total daily household consumption estimates from each household survey are provided for better interpretability of mean absolute error. Abbreviations: FCS-HH (2013 Food Consumption Survey), HSES-HH (2012/2014 Household Socio-Economic Survey), MAE (mean absolute error), HH (household), IU (international unit; 40 IU = 1 µg). Statistics are survey-weighted.

Table S3.7: Mean bias of household disaggregation methods in estimating ranks of food group and nutrient intakes and intake densities (per 100 kcal) across 14 age-sex groups (Aims 2 and 3)

	Validation Metric:	**Mean Rank Bias in Intake**						**Mean Rank Bias in Intake Density (per 100 kcal)**					
	Household Survey:	**FCS-HH (n=1012**			**HSES-HH (n=9424)**			**FCS-HH (n=1012**			**HSES-HH (n=9424)**		
	Disaggregation Method:	**SD1**	**SD2**	**AME**	**SD1**	**SD2**	**AME**	**SD1**	**SD2**	**AME**	**SD1**	**SD2**	**AME**
Food Groups	Animal fat, eggs, and dairy products (g)	5.1	5.0	5.1	4.4	5.0	5.0	3.9	3.6	4.6	4.3	4.6	5.3
	Baked and fried flour products (g)	5.6	6.0	4.7	5.7	5.7	5.4	4.0	4.1	3.3	4.9	4.6	4.6
	Flours, grains, and noodles (g)	3.9	4.4	2.9	3.4	5.4	4.7	3.4	4.1	2.3	1.6	3.0	1.9
	Fruits and non-tuber vegetables (g)	5.6	5.6	5.6	5.6	5.7	6.3	5.3	4.9	3.7	3.1	3.1	4.6
	Meat, fish, and poultry (g)	5.1	5.1	3.6	3.6	4.6	4.4	5.6	5.6	4.6	3.1	3.3	2.9
	Milk (except fermented) (g)	2.7	3.1	3.0	2.0	2.3	2.7	1.6	1.7	3.0	3.6	4.0	4.0
	Salt (g)	4.1	4.0	2.4	4.9	4.9	4.6	3.6	3.6	3.4	5.3	5.3	3.6
	Starchy root vegetables (g)	4.9	5.1	5.0	3.6	4.7	5.4	4.9	4.4	3.1	2.4	2.4	2.1
	Sugar and sweeteners (g)	3.9	4.3	4.0	4.9	5.3	5.3	4.3	4.3	4.3	4.0	4.4	6.1
	Tea or coffee (solid equivalent) (g)	5.0	4.7	4.3	4.3	4.3	3.7	4.4	4.4	4.4	3.6	3.4	4.6
	Vegetable oils (any) (g)	4.6	5.0	4.6	2.0	3.4	4.0	4.1	4.3	4.1	3.4	3.3	4.1
Macronutrients	Energy (kcal)	4.0	4.3	3.1	4.7	5.3	4.7	N/A	N/A	N/A	N/A	N/A	N/A
	Carbohydrates (g)	3.3	4.1	3.3	4.6	5.3	4.7	3.4	3.3	3.9	4.7	4.0	3.6
	Protein (g)	5.0	5.0	4.0	4.7	5.1	5.0	4.6	4.3	3.3	3.0	3.0	4.1
	Total fat (g)	5.7	5.4	4.1	4.9	4.9	5.0	4.1	4.6	4.9	4.6	4.0	4.1
	Alcohol (g)	3.3	3.1	2.9	2.2	2.1	3.1	3.4	3.1	4.3	1.9	1.8	2.1
	Water (g)	5.9	5.6	4.6	5.1	5.0	4.7	4.4	4.4	4.0	3.7	3.4	3.9
	Fiber (g)	3.6	4.1	3.1	4.1	4.9	4.3	4.6	4.0	5.0	5.9	5.0	5.3
	Phytosterols (mg)	4.7	4.9	3.4	4.9	5.1	4.6	5.1	5.6	6.0	4.7	4.4	4.9
Vitamins	Thiamin (mg)	4.3	4.7	3.7	4.7	4.7	4.3	3.4	3.4	4.3	3.7	3.3	4.0
	Riboflavin (mg)	6.0	6.0	4.7	4.7	4.9	4.7	3.0	3.1	3.1	4.4	4.4	3.7
	Niacin (mg)	5.0	5.0	3.6	4.1	4.9	4.3	6.4	6.3	6.3	5.1	4.6	5.7
	Pantothenic acid (mg)	5.6	5.4	4.1	4.9	4.9	4.9	5.0	5.0	4.0	4.0	4.0	5.1
	Vitamin B6 (mg)	4.6	4.6	3.6	4.7	4.7	4.4	6.0	5.7	5.0	5.1	4.9	4.0
	Folate (µg)	4.3	4.7	3.4	4.7	5.0	4.7	6.0	5.6	4.9	5.0	5.3	3.6
	Vitamin B12 (µg)	6.6	6.6	3.9	5.0	4.9	4.3	6.7	6.7	5.9	4.9	4.9	4.6
	Vitamin C (mg)	5.7	5.7	5.3	4.9	5.7	6.3	4.6	5.3	4.9	3.4	3.1	4.6
	Vitamin A (µg)	6.6	6.7	3.9	5.3	5.3	4.1	6.9	7.0	6.0	6.4	6.4	6.0
	Vitamin D (IU)	4.7	4.7	4.4	5.9	5.9	4.7	4.3	4.4	3.9	4.9	5.0	4.7
	Vitamin E (mg)	4.6	5.3	4.0	3.4	4.6	4.0	6.1	5.7	6.0	6.3	6.1	5.7
Minerals	Calcium (mg)	6.6	6.4	5.9	6.1	6.0	5.9	3.1	2.6	3.9	4.1	4.3	3.9
	Copper (mg)	4.6	5.1	2.7	4.1	5.1	4.3	6.0	6.0	6.3	5.6	6.0	5.3
	Iron (mg)	3.9	4.6	2.9	4.7	4.6	4.6	5.6	5.1	5.7	4.6	4.4	4.6
	Magnesium (mg)	4.7	5.0	4.1	5.1	5.3	5.0	3.4	3.1	3.4	2.9	3.0	3.3
	Manganese (mg)	3.6	4.1	3.1	4.9	5.0	4.6	4.9	4.6	6.0	5.1	4.6	5.6
	Phosphorus (mg)	5.4	5.3	4.7	5.1	5.1	5.0	1.7	1.6	3.1	4.0	4.3	4.3
	Potassium (mg)	5.0	5.0	4.7	5.1	5.1	5.1	3.3	3.4	4.3	3.6	4.1	4.0
	Zinc (mg)	5.3	5.0	4.1	4.7	5.0	5.0	4.6	4.3	4.3	3.0	2.9	4.4

Table S3.7 (continued)

Green-Yellow-Red shading indicates the magnitude of mean bias in estimated ranks of intake (Green: minimum observed mean rank bias; Yellow: median; red: maximum), and Blue-Yellow-Red shading indicates magnitude of mean bias in estimated ranks of intake density (per 100 kcal) (Blue: minimum observed absolute mean rank bias; Yellow: median; Red: maximum). Abbreviations: FCS-HH (2013 Food Consumption Survey), HSES-HH (2012/2014 Household Socio-Economic Survey), SD1 (unadjusted statistical disaggregation method), SD2 (AME-like statistical disaggregation method), IU (international unit; 40 IU = 1 µg). Statistics are survey weighted.

Table S3.8: In-sample fit statistics for increasingly complex predictive models of individuals' dietary intakes and intake densities (per 100 kcal) in the FCS-24 (Aim 4)

	Measurement Type:	**Nutrient Intake**																	
	Validation Metric:	**1 / (Residual Deviance / Null Deviance) * 100**							**Mean Absolute Error**										
	Model Designation:	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**	**(SD1)**	**(SD2)**	**(AME)**	**Intake**
Macronutrients	Energy (kcal)	53.6	52.9	51.9	59.3	66.0	68.3	71.8	229	231	229	209	191	185	178	384	1344	1095	1864
	Carbohydrates (g)	44.7	45.7	44.8	52.4	60.2	67.4	62.4	35.65	35.58	35.92	32.63	30.28	27.49	29.57	56.58	136.63	126.35	241.10
	Protein (g)	54.1	55.3	56.7	60.8	68.2	69.7	71.5	8.83	8.67	8.75	8.47	7.25	7.12	7.01	20.85	65.01	50.15	70.09
	Total fat (g)	40.8	42.5	45.8	50.1	55.0	64.9	65.3	9.92	9.86	9.62	9.49	8.40	7.77	7.72	23.12	69.22	47.73	66.38
	Alcohol (g)	91.9	92.0	94.6	94.6	95.4	99.1	99.0	0.73	0.68	0.33	0.30	0.41	0.30	0.31	1.60	1.58	1.62	1.47
	Water (g)	29.0	34.1	30.0	43.4	48.0	61.7	64.1	133.46	129.52	129.21	116.17	110.92	99.64	95.32	255.61	725.61	572.34	572.27
	Fiber (g)	48.8	48.1	48.2	56.0	61.6	71.5	72.8	1.1	1.1	1.1	1.0	1.0	0.9	0.9	2.3	6.5	5.8	8.6
	Phytosterols (mg)	56.3	55.4	53.5	60.1	68.0	75.0	75.7	50	51	51	47	42	40	42	140	316	262	424
Vitamins	Thiamin (mg)	37.9	37.9	39.6	47.2	54.8	62.4	63.5	0.107	0.108	0.104	0.097	0.088	0.084	0.085	0.252	0.727	0.567	0.784
	Riboflavin (mg)	31.0	35.7	31.8	40.5	47.0	70.2	71.8	0.207	0.196	0.201	0.181	0.174	0.137	0.141	0.468	1.266	1.027	1.220
	Niacin (mg)	57.2	58.5	60.2	64.5	67.3	74.1	75.4	1.394	1.389	1.352	1.273	1.187	1.135	1.162	4.066	13.031	9.522	13.064
	Pantothenic acid (mg)	37.6	37.7	38.5	44.9	52.2	66.1	69.6	0.443	0.450	0.458	0.430	0.392	0.334	0.334	1.087	3.143	2.421	3.111
	Vitamin B6 (mg)	44.7	44.8	46.1	52.0	62.2	69.8	69.7	0.103	0.104	0.099	0.094	0.084	0.075	0.079	0.235	0.692	0.542	0.628
	Folate (µg)	41.1	40.2	38.2	48.3	52.9	72.4	72.4	25	25	24	22	22	17	17	37	100	81	132
	Vitamin B12 (µg)	67.4	68.7	71.9	73.2	76.1	90.5	91.5	1.10	0.96	1.06	1.04	0.95	0.61	0.61	2.96	4.44	3.00	6.35
	Vitamin C (mg)	42.5	42.1	46.5	49.8	56.1	83.4	83.2	1.5	1.4	1.4	1.3	1.2	0.8	0.8	7.2	24.3	20.8	12.4
	Vitamin A (µg)	59.0	62.7	63.8	65.3	67.7	90.1	88.0	109	95	95	95	97	53	59	227	389	266	448
	Vitamin D (IU)	31.0	34.6	31.7	36.0	46.5	77.4	78.1	6	6	6	6	6	4	4	13	33	24	26
	Vitamin E (mg)	28.2	27.7	29.1	57.3	63.0	64.5	70.0	0.97	0.98	0.96	0.75	0.69	0.67	0.65	1.73	5.35	4.39	5.28
Minerals	Calcium (mg)	29.2	34.2	33.9	50.1	55.0	68.7	68.5	112	108	109	95	89	74	78	227	569	483	432
	Copper (mg)	58.6	59.8	60.4	62.7	67.7	85.2	84.7	0.152	0.153	0.149	0.138	0.135	0.097	0.101	0.325	0.681	0.550	0.986
	Iron (mg)	49.4	47.8	51.9	55.4	61.5	68.7	68.6	1.34	1.35	1.29	1.27	1.15	1.10	1.12	2.59	7.60	5.98	10.03
	Magnesium (mg)	49.8	49.8	48.3	57.9	62.1	69.2	70.5	23	23	24	21	20	18	18	51	143	116	168
	Manganese (mg)	52.6	52.4	50.7	61.1	65.0	70.6	72.1	0.292	0.295	0.297	0.263	0.249	0.239	0.240	0.495	1.337	1.239	2.172
	Phosphorus (mg)	52.5	54.2	52.9	58.9	62.3	70.6	69.2	120	117	117	109	104	97	99	279	846	667	907
	Potassium (mg)	39.0	39.0	36.9	43.2	48.7	63.8	63.7	205	204	210	199	182	160	159	491	1657	1223	1436
	Zinc (mg)	61.9	63.2	62.7	67.9	71.8	73.2	74.7	1.14	1.17	1.15	1.07	0.99	0.98	0.99	3.40	11.30	7.88	10.85

Table S3.8 (continued)

	Measurement Type:	**Nutrient Intake Density (per 100 kcal)**																	
	Validation Metric:	**1 / (Residual Deviance / Null Deviance) * 100**							**Mean Absolute Error**										
	Model Designation:	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**	**(SD1)**	**(SD2)**	**(AME)**	**Density**
Macronutrients	Energy (kcal)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Carbohydrates (g)	6.7	11.1	9.8	24.0	35.3	47.3	45.9	0.856	0.856	0.853	0.798	0.734	0.697	0.699	1.358	1.575	1.135	12.920
	Protein (g)	13.6	14.7	14.4	26.3	39.5	51.8	52.8	0.292	0.296	0.297	0.283	0.240	0.228	0.235	0.418	0.517	0.370	3.777
	Total fat (g)	23.2	25.0	25.7	34.9	48.4	61.5	57.4	0.291	0.285	0.287	0.269	0.243	0.226	0.225	0.569	0.703	0.378	3.574
	Alcohol (g)	88.3	88.5	91.9	92.4	92.6	97.4	96.8	0.029	0.031	0.020	0.019	0.017	0.014	0.014	0.068	0.066	0.064	0.067
	Water (g)	14.2	18.7	12.9	24.4	35.4	59.1	59.3	6.566	6.496	6.620	6.373	5.940	4.608	4.513	8.816	11.706	11.055	31.081
	Fiber (g)	27.6	31.7	30.7	36.1	47.0	67.7	65.6	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.08	0.06	0.10	0.47
	Phytosterols (mg)	16.7	17.6	18.9	27.2	37.9	69.8	64.9	2.0	2.0	2.1	2.0	1.8	1.4	1.6	5.0	3.5	3.3	22.9
Vitamins	Thiamin (mg)	17.7	19.1	19.3	32.1	39.0	61.2	65.0	0.0039	0.0039	0.0040	0.0037	0.0034	0.0028	0.0028	0.0062	0.0063	0.0065	0.0426
	Riboflavin (mg)	11.6	13.9	13.5	25.8	40.2	71.0	76.0	0.0096	0.0096	0.0095	0.0089	0.0088	0.0061	0.0053	0.0138	0.0163	0.0122	0.0661
	Niacin (mg)	40.5	41.8	39.5	45.7	52.9	67.2	70.9	0.0612	0.0619	0.0630	0.0578	0.0545	0.0438	0.0452	0.1236	0.1432	0.1170	0.7093
	Pantothenic acid (mg)	16.6	13.4	12.7	23.7	38.4	63.8	70.5	0.0191	0.0191	0.0195	0.0183	0.0169	0.0129	0.0116	0.0292	0.0327	0.0314	0.1686
	Vitamin B6 (mg)	43.6	45.6	47.1	51.9	54.3	71.4	71.7	0.0047	0.0047	0.0047	0.0044	0.0044	0.0033	0.0034	0.0093	0.0102	0.0101	0.0342
	Folate (µg)	17.1	19.8	20.3	28.2	32.8	66.2	65.8	0.9	0.9	0.9	0.8	0.8	0.6	0.6	1.0	1.0	1.0	7.1
	Vitamin B12 (µg)	57.4	59.7	57.4	61.3	68.7	85.5	86.3	0.057	0.057	0.058	0.053	0.046	0.036	0.036	0.137	0.131	0.091	0.339
	Vitamin C (mg)	55.6	55.0	55.1	59.2	64.5	79.8	79.4	0.11	0.11	0.11	0.11	0.10	0.08	0.08	0.35	0.56	0.60	0.70
	Vitamin A (µg)	53.3	57.3	56.9	59.6	60.9	87.8	86.2	5.3	5.1	5.0	4.7	4.8	2.8	3.1	11.0	11.5	8.4	23.7
	Vitamin D (IU)	42.1	46.7	41.2	46.1	54.9	82.2	80.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.6	0.7	0.4	1.4
	Vitamin E (mg)	9.7	13.0	7.7	39.5	50.3	62.1	57.7	0.043	0.043	0.042	0.034	0.032	0.028	0.031	0.057	0.069	0.091	0.286
Minerals	Calcium (mg)	28.1	32.9	33.8	48.4	57.4	73.4	72.7	5.6	5.6	5.5	4.8	4.5	3.6	3.6	7.8	9.4	7.9	23.6
	Copper (mg)	47.0	50.9	48.8	50.8	54.5	84.6	85.0	0.0068	0.0074	0.0077	0.0071	0.0078	0.0041	0.0043	0.0151	0.0133	0.0129	0.0528
	Iron (mg)	14.7	14.9	16.1	24.9	33.2	63.7	64.0	0.045	0.045	0.045	0.043	0.040	0.030	0.032	0.056	0.054	0.059	0.541
	Magnesium (mg)	21.1	21.1	21.7	27.3	27.8	60.8	56.3	0.6	0.7	0.7	0.7	0.6	0.5	0.5	1.0	1.0	1.1	9.1
	Manganese (mg)	41.3	43.1	44.6	49.1	55.6	64.6	66.9	0.0093	0.0091	0.0097	0.0086	0.0086	0.0072	0.0071	0.0146	0.0149	0.0200	0.1171
	Phosphorus (mg)	31.8	34.1	32.6	43.5	48.9	70.0	70.3	3.6	3.6	3.7	3.3	3.2	2.5	2.5	4.9	6.5	4.7	48.9
	Potassium (mg)	16.8	16.6	16.5	22.5	32.9	54.2	54.5	8.6	8.6	8.8	8.5	8.2	6.6	6.4	12.6	19.6	15.7	78.1
	Zinc (mg)	24.9	24.6	23.8	35.2	42.5	56.9	49.7	0.053	0.053	0.053	0.048	0.045	0.041	0.044	0.099	0.126	0.076	0.587

Table S3.8 (continued)

See Table 3.4 for detailed descriptions of models 1-5. Brief description of variable categories considered for selection in each model: (1) Household and individual demographic, socioeconomic, and lifestyle characteristics, (2) Model 1 variables + quantitative total household consumption of food groups and nutrients, (3) Model 2 variables + individuals' self-evaluation of nutrition knowledge and its application to their lives, (4a) Model 3 variables + cursory qualitative 24-hour recall and assessment of eating behaviors, (4b) Model 3 variables + cursory semiquantitative 24-hour recall and assessment of eating behaviors, (4c) Model 3 variables + detailed semiquantitative 24-hour recall, (5) Model 4 variables + measured anthropometry. For comparison with mean absolute error of prediction models 1-5, mean absolute error of unadjusted and AME-like statistical disaggregation and adult male equivalent methods applied to the FCS-HH are provided in columns "(SD1)", "(SD2)", and "(AME)", respectively. Mean dietary intake and intake density from the FCS-24 are also provided in the "Intake" and "Density" columns for better interpretability of all mean absolute error estimates. Green-Yellow-Red shading indicates the magnitude of mean absolute error in predicting dietary nutrient intake proportional to mean observed dietary intake (Green: minimum absolute error; Yellow: median; Red: maximum) and Blue-Yellow-Red shading indicates the magnitude of mean absolute error in predicting dietary nutrient intake density proportional to mean observed dietary intake density (per 100 kcal) (Blue: minimum absolute error; Yellow: median; Red: maximum). Abbreviations: FCS-HH (2013 Food Consumption Survey), FCS-24 (nested 24-hour recall), IU (international unit; 40 IU = 1 µg).

Table S3.9: Mean absolute error of alternate prediction methods of individuals' dietary intake densities of nutrients in the FCS-24: direct prediction of nutrient densities (left) vs. estimation based on separate prediction of nutrient intake and energy intake (right) (Aim 4)

	Prediction Method:	**Direct Prediction of Nutrient Intake Densities**							**Separate Prediction of Nutrient and Energy Intake**							
	Model Designation:	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**	**1**	**2**	**3**	**4a**	**4b**	**4c**	**5**	**Density**
Macronutrients	Energy (kcal)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Carbohydrates (g)	0.856	0.856	0.853	0.798	0.734	0.697	0.699	0.833	0.879	0.814	0.784	0.814	0.733	0.728	12.920
	Protein (g)	0.292	0.296	0.297	0.283	0.240	0.228	0.235	0.279	0.284	0.280	0.271	0.262	0.229	0.229	3.777
	Total fat (g)	0.291	0.285	0.287	0.269	0.243	0.226	0.225	0.288	0.280	0.277	0.274	0.273	0.215	0.212	3.574
	Alcohol (g)	0.029	0.031	0.020	0.019	0.017	0.014	0.014	0.029	0.032	0.018	0.019	0.018	0.012	0.016	0.067
	Water (g)	6.566	6.496	6.620	6.373	5.940	4.608	4.513	6.292	6.100	6.289	5.977	5.718	4.529	4.441	31.081
	Fiber (g)	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.47
	Phytosterols (mg)	2.0	2.0	2.1	2.0	1.8	1.4	1.6	1.9	1.9	2.1	1.9	1.8	1.6	1.8	22.9
Vitamins	Thiamin (mg)	0.0039	0.0039	0.0040	0.0037	0.0034	0.0028	0.0028	0.0038	0.0037	0.0038	0.0034	0.0033	0.0028	0.0027	0.0426
	Riboflavin (mg)	0.0096	0.0096	0.0095	0.0089	0.0088	0.0061	0.0053	0.0090	0.0090	0.0090	0.0086	0.0083	0.0062	0.0057	0.0661
	Niacin (mg)	0.0612	0.0619	0.0630	0.0578	0.0545	0.0438	0.0452	0.0615	0.0610	0.0615	0.0600	0.0557	0.0462	0.0469	0.7093
	Pantothenic acid (mg)	0.0191	0.0191	0.0195	0.0183	0.0169	0.0129	0.0116	0.0179	0.0177	0.0181	0.0176	0.0169	0.0138	0.0125	0.1686
	Vitamin B6 (mg)	0.0047	0.0047	0.0047	0.0044	0.0044	0.0033	0.0034	0.0046	0.0045	0.0046	0.0044	0.0041	0.0035	0.0035	0.0342
	Folate (µg)	0.9	0.9	0.9	0.8	0.8	0.6	0.6	0.9	0.9	0.9	0.8	0.9	0.6	0.6	7.1
	Vitamin B12 (µg)	0.057	0.057	0.058	0.053	0.046	0.036	0.036	0.061	0.059	0.060	0.054	0.051	0.036	0.038	0.339
	Vitamin C (mg)	0.11	0.11	0.11	0.11	0.10	0.08	0.08	0.11	0.11	0.11	0.11	0.10	0.08	0.08	0.70
	Vitamin A (µg)	5.3	5.1	5.0	4.7	4.8	2.8	3.1	5.4	4.9	5.0	4.7	4.6	3.0	3.2	23.7
	Vitamin D (IU)	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	1.4
	Vitamin E (mg)	0.043	0.043	0.042	0.034	0.032	0.028	0.031	0.042	0.041	0.041	0.033	0.032	0.030	0.031	0.286
Minerals	Calcium (mg)	5.6	5.6	5.5	4.8	4.5	3.6	3.6	5.4	5.3	5.5	4.7	4.6	3.6	3.6	23.6
	Copper (mg)	0.0068	0.0074	0.0077	0.0071	0.0078	0.0041	0.0043	0.0074	0.0074	0.0076	0.0071	0.0070	0.0048	0.0045	0.0528
	Iron (mg)	0.045	0.045	0.045	0.043	0.040	0.030	0.032	0.042	0.042	0.042	0.041	0.040	0.030	0.031	0.541
	Magnesium (mg)	0.6	0.7	0.7	0.7	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.5	0.5	9.1
	Manganese (mg)	0.0093	0.0091	0.0097	0.0086	0.0086	0.0072	0.0071	0.0093	0.0093	0.0096	0.0094	0.0082	0.0080	0.0085	0.1171
	Phosphorus (mg)	3.6	3.6	3.7	3.3	3.2	2.5	2.5	3.5	3.4	3.5	3.2	3.4	2.5	2.9	48.9
	Potassium (mg)	8.6	8.6	8.8	8.5	8.2	6.6	6.4	8.2	8.2	8.4	8.2	8.1	6.2	6.2	78.1
	Zinc (mg)	0.053	0.053	0.053	0.048	0.045	0.041	0.044	0.051	0.051	0.051	0.047	0.045	0.042	0.042	0.587

Table S3.9 (continued)

Columns under "Separate Prediction of Nutrient and Energy Intake" present mean absolute error of nutrient intake densities estimated by separately predicting nutrient intake and energy intake, dividing predicted nutrient intake by predicted energy intake, and comparing the results to observed dietary intake measurements in the FCS-24. Columns under "Direct Prediction of Nutrient Intake Densities" are reproduced from Table 3.8 for comparison. See Table 3.4 for detailed descriptions of models 1-5. Brief description of variable categories considered for selection in each model: (1) Household and individual demographic, socioeconomic, and lifestyle characteristics, (2) Model 1 variables + quantitative total household consumption of food groups and nutrients, (3) Model 2 variables + individuals' self-evaluation of nutrition knowledge and its application to their lives, (4a) Model 3 variables + cursory qualitative 24-hour recall and assessment of eating behaviors, (4b) Model 3 variables + cursory semiquantitative 24-hour recall and assessment of eating behaviors, (4c) Model 3 variables + detailed semiquantitative 24-hour recall, (5) Model 4 variables + measured anthropometry. Mean dietary intake density from the FCS-24 is provided in the "Density" column for better interpretability of all mean absolute error estimates. Blue-Yellow-Red shading indicates the magnitude of mean absolute error in predicting dietary nutrient intake density proportional to mean observed dietary intake density (per 100 kcal) (Blue: minimum absolute error; Yellow: median; Red: maximum). Abbreviations: FCS-24 (nested 24-hour recall of the 2013 Food Consumption Survey), IU (international unit; 40 IU = 1 µg).