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Original Research

Associations of Diet Quality, Socioeconomic Factors, and Nutritional Status with Gestational Weight Gain among Pregnant Women in Dar es Salaam, Tanzania

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A B S T R A C T

Background: Gestational weight gain (GWG) is a modifiable factor associated with maternal and child health outcomes, but the relationship between diet quality and GWG has not been evaluated using metrics validated for low-income and middle-income countries (LMICs).
Objective: This study aimed to investigate relationships between diet quality, socioeconomic characteristics, and GWG adequacy using the novel Global Diet Quality Score (GDQS), the first diet quality indicator validated for use across LMIC.
Methods: Weights of pregnant women enrolled between 12 and 27 wk of gestation ($N = 7577$) were recorded in Dar es Salaam, Tanzania, from 2001 to 2005 during a prenatal micronutrient supplementation trial. GWG adequacy was the ratio of measured GWG to Institute of Medicine–recommended GWG, categorized into severely inadequate (<70%), inadequate (70 to <90%), adequate (90 to <125%), or excessive (≥125%). Dietary data were collected using 24-h recalls. Multinomial logit models were used to estimate relationships between GDQS tercile, macronutrient intake, nutritional status, and socioeconomic characteristics and GWG.
Results: GDQS scores in the second [relative risk (RR): 0.82; 95% confidence interval (CI): 0.70, 0.97] tercile were associated with lower risk of inadequate weight gain than those in the first tercile. Increased protein intake was associated with higher risk of severely inadequate GWG (RR: 1.06; 95% CI: 1.02, 1.09). Nutritional status and socioeconomic factors were associated with GWG: underweight prepregnancy BMI (in kg/m^2) with a higher risk of severely inadequate GWG (RR: 1.49; 95% CI: 1.12, 1.99), overweight or obese BMI with a higher risk of excessive GWG (RR: 6.80; 95% CI: 5.34, 8.66), and a higher education (RR: 0.61; 95% CI: 0.42, 0.89), wealth (RR: 0.68; 95% CI: 0.48, 0.80), and height (RR: 0.96; 95% CI: 0.95, 0.98) with a lower risk of severely inadequate GWG.
Conclusions: Dietary indicators showed few associations with GWG. However, stronger relationships were revealed between GWG, nutritional status, and several socioeconomic factors.
This trial was registered at clinicaltrials.gov as NCT00197548.

Keywords: gestational weight gain, pregnant women, diet quality, low-income and middle-income countries

Abbreviations: AMDR, acceptable macronutrient distribution range; DQI, diet quality index; GWG, gestational weight gain; IOM, Institute of Medicine; LMICs, low-income and middle-income countries; MDD-W, minimum diet diversity score for women; MDQS, maternal diet quality score; MMS, multiple micronutrient supplement.

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Introduction

Weight gain during pregnancy can be modified by intervention and has important implications for both maternal and offspring health outcomes [1]. To guide pregnant women toward optimal gestational weight gain (GWG), the Institute of Medicine (IOM) recommends ranges of appropriate GWG by prepregnancy BMI (in kg/m^2) [2]. Gaining inadequate weight compared with these standards is associated with intrauterine growth retardation, reduced birth length [3], small for gestational age, preterm birth, and low birth weight [4,5]. Excessive GWG similarly carries risks, such as macrosomia and large for gestational age for offspring and postpartum hemorrhage, gestational diabetes, preeclampsia, hypertensive pregnancy, cesarian section, and postpartum weight retention for mothers [1,4,5]. Although the IOM guidelines were developed in the United States and not directly applicable in low-income and middle-income countries (LMICs) [2], similar associations between GWG outside of the IOM recommendations and adverse outcomes have been found across high-income settings and LMICs [6].

The effects of inadequate or excessive GWG on offspring are long-term and are associated with intergenerational transmission of both undernutrition and obesity [7]. Adverse birth outcomes due to suboptimal GWG are associated with growth faltering [8], which leads to short maternal stature and subsequent intrauterine growth restriction. In addition, low birth weight associated with GWG is linked with increased risk of obesity and related chronic diseases later in life [1]. Given the high prevalence of inadequate weight gain across many LMICs [9], and the risk of intergenerational transmission of malnutrition, identifying factors that can support optimal GWG in LMIC is important.

Dietary intake and nutrition are modifiable factors that have been shown to influence GWG in both high-income countries and LMICs [10,11]. In LMICs, studies in this domain generally fall into 3 categories: *1*) assessment of the effects of supplementation trials aimed at improving nutritional status on GWG, *2*) determining how specific micronutrient or macronutrient intake is related to GWG, and *3*) use of various diet quality and diversity scores to investigate relationships between overall diet quality and GWG. Results from these studies have shown that increased caloric intake [12], and supplementation with lipid-based nutrient supplements or multiple micronutrient supplements are associated with improvements in GWG [13–15], as is scoring higher on the diet quality index (DQI) or DQI for pregnancy [16,17], the maternal diet quality score (MDQS) [18], the minimum diet diversity score for women (MDD-W) [19,20], and the Prime Diet Quality Score (PDQS) [21].

However, these studies are either limited by assessment of caloric intake instead of overall diet quality or the indices used to assess diet quality have several limitations that should be addressed to allow for stronger and more generalizable recommendations about dietary patterns and GWG in LMICs. First, the DQI for pregnancy was designed using guidelines from the United States, and the MDQS was developed using the Mexican dietary guidelines [18,22]; thus neither of these scales have been validated for use across multiple LMIC contexts. Second, these diet quality indices assign more points to healthy foods but do not penalize diets for consumption of unhealthy foods.

We used a novel dietary quality score developed in 2018 by a consortium of researchers at the Harvard T.H. Chan School of Public Health and partner institutions, to assess the relationship between diet quality and GWG among pregnant women in Tanzania. Not only the Global Diet Quality Score (GDQS) is validated for use in evaluating nutritional outcomes across multiple regions and contexts, but also it improves on older measures of diet quality by considering the diversity of local diets globally, including portion sizes in scoring food groups, and assessing both nutrient adequacy and factors that may increase the risk of chronic diseases [23]. The index penalizes diets for unhealthy foods, awards more points for healthy foods, and considers the U-shaped relationship for some foods that are unhealthy if consumed in high quantities but healthy in small quantities. Thus, it allows analyses of the relative importance of healthy compared with unhealthy foods in relation to both inadequate and excessive GWG. The main objective of this article focused on relationships between diet quality and GWG. However, other modifiable factors may also be associated with GWG and are important to understand when interpreting the relationship between diet quality and GWG. Therefore, we also examined the associations of other nutritional, sociodemographic, and socioeconomic factors with GWG.

Methods

Study design and population

We analyzed data from 8428 pregnant women participating in a double-blind randomized controlled trial testing the effects of daily multiple micronutrient supplementation (MMS) during pregnancy on perinatal outcomes. Women recruited from 9 antenatal clinics in Dar es Salaam between August 2001 and July 2004 were followed up monthly until the 32nd wk of pregnancy, every 2 wk until week 36, and weekly thereafter until 6 wk postpartum. Inclusion criteria included negative test results for human immunodeficiency virus, gestational age between 12 and 27 wk based on assisted recall of the date of the last menstrual period using calendars and important local dates, maternal age of $\geq$18 y, and intention to remain in Dar es Salaam for a minimum of 1 y after delivery.

After providing written informed consent, participants were randomly assigned to receive daily tablets of either a placebo or MMS containing vitamin B-1 (thiamine) (20 mg), vitamin B-2 (riboflavin) (20 mg), vitamin B-6 (25 mg), niacin (100 mg), vitamin B-12 (50 μg), vitamin C (500 mg), vitamin E (30 mg), and folic acid (0.8 mg). In addition, all women received sulfadoxine-pyrimethamine for malaria prevention and daily supplements of 0.25 mg folic acid and 60 mg ferrous sulfate, as mandated by standard prenatal care procedures in Tanzania. Further details of the original trial can be found in the original publication [24].

During the original consent process, participants agreed to future use of data and specimens that were collected to address additional research questions outside the scope of the primary study aims. Participants were provided access to the study clinics at all times for their health needs during the study and were reimbursed for the costs of transportation to come to study visits. Women were provided with standard of care during their antenatal and postnatal periods following the guidelines of the Tanzanian Ministry of Health. Although GWG was not monitored in real time, so those with severely inadequate GWG were not identified until after the study, all women received counseling about optimal diet and were provided with prenatal iron and folic acid supplements, malaria prophylaxis, and other intervention per standard prenatal care guidelines in Tanzania. At the end of data collection, data were anonymized, and this anonymized data set was used by all researchers in Dar es Salaam and Boston involved in both primary and secondary analyses. Benefits from study participation included access to study physicians and nurses regardless of the assigned study arm and standard of care. Findings from the study were disseminated at public forums in Tanzania and shared with Tanzanian health authorities, including personnel from the Ministry of Health, district officials in Dar es Salaam, and staff at clinics where the study was conducted.

Data collection

Anthropometric data, such as weight (in kg), height (in cm), mid–upper arm circumference (in cm), and triceps skinfolds (in cm), were collected at the baseline and each follow-up visit by trained research nurses. Weight was measured to the nearest 100 g using balance scales, whereas women were wearing light clothing and no shoes, and height was measured to the nearest 0.1 cm using a stadiometer, with head covers and shoes removed. Clinical examinations were performed by nurses monthly, and data were collected at the baseline on demographics, socioeconomic status, and behavioral and reproductive factors, including complete medical history at enrollment (all self-reported). Diets were assessed using multiple 24-h recalls conducted at study recruitment and each monthly follow-up visit until 36 wk of gestation (median number of recalls available for participants was 4). Participants were asked to cite all food consumed in the previous 24-h period (from the time they woke up until the time they went to bed) and estimate portion sizes using common household utensils.

Diet quality

To assess overall diet quality as the primary exposure, we constructed a GDQS for each 24-h recall by assigning each food reportedly consumed during the recall period to one of the 25 categories (Supplemental Table 1). If multiple recalls were performed for a given participant, mean GDQS scores were calculated based on all 24-h recalls performed. Quantities of each food consumed were estimated in grams per day by multiplying utensil capacity by the number of servings reported using the utensil used for the food. Points were then assigned according to GDQS guidelines based on the quantities of each food consumed to obtain a discrete score ranging from 0 to 49. GDQS guidelines are replicated in Supplemental Table 1 [23]. GDQS was categorized into terciles instead of the typical GDQS categories of elevated risk of nutritional inadequacy (GDQS $<$ 15), moderate risk of nutritional inadequacy (GDQS of $\geq$15 and $<$23), or low risk of nutritional inadequacy (GDQS $\geq$ 23) owing to lack of heterogeneity among the preset categories (100% of participants fell into the high risk of nutritional deficiency category).

Foods reported as mixed dishes were assigned GDQS points for each component of the dish based on adjusted portion size estimations using the proportion of the dish made up of each component as estimated by recipes from the food composition tables. In addition to an overall GDQS score, GDQS+ and GDQS− scores were calculated using only the healthy foods (GDQS+) or only the unhealthy foods (GDQS−).

To allow comparison with previous studies, we also looked at overall diet diversity using the MDD-W indicator. Diet diversity was coded according to the 2021 MDD-W guide by FAO [25], as a score ranging from 0 to 10, with each point corresponding to one of the 10 MDD-W food groups. These food groups include grains, white roots and tubers, and plantains; pulses, nuts and seeds; milk and milk products; meat; poultry and fish; eggs; dark green leafy vegetables; other vitamin A-rich fruits and vegetables; other vegetables; and other fruits [25]. The MDD-W was computed as the sum of food groups consumed by a woman in the previous 24 h. If multiple 24-h recalls were performed, the mean MDD-W over all recalls was used. We categorized the MDD-W as follows: $<$2, 2 to $<$3, 3 to $<$4, or $\geq$4. Further, we assessed it as a dichotomous indicator for meets minimum diet diversity ($\geq$5 food groups consumed) or does not ($<$5 food groups consumed).

Finally, we assessed the relationship between macronutrient intake and GWG adequacy. We used food composition tables of foods commonly consumed in Dar es Salaam, established around the time of original data collection [26], to calculate nutrient intakes per day from foods consumed during the 24-h recall period. Total energy intake was summed in kilocalories, and macronutrient intake was analyzed as the percentage of total kilocalories contributed by protein, fat, and carbohydrates. Acceptable macronutrient distribution ranges (AMDRs) were calculated as 45%–65% of total energy contributed by carbohydrates, 10%–30% contributed by protein, and 20%–35% contributed by fat, according to IOM guidelines [27]. Intakes for each participant were calculated as the cumulative means of all repeated 24-h recalls.

Outcomes: maternal weight and GWG

Calculation of prepregnancy BMI

Because women were enrolled during the second trimester (12–27 wk of gestation), 98% of women in our sample did not have data for first trimester weights. Thus, first trimester weights were imputed using restricted cubic splines for all women at 9 wk of gestation [midpoint of first trimester and starting point for INTERGROWTH-21st GWG standards [28]] to serve as a proxy for prepregnancy weight and used to calculate prepregnancy BMI. Additional details of the imputation models can be found in previously published work [29]. Prepregnancy BMI was calculated as the imputed or observed first trimester weight (in kg) divided by the square of height (in square m). Supplemental Table 2 summarizes BMI classifications based on World Health Organization (WHO) criteria for women aged $>$20 y. For those aged $<$20 y at enrollment (adolescents), WHO growth references were used to calculate BMI-for-age z-scores and classify women with <-2 SD as underweight, -2 SD to $<$1 SD as normal weight, 1 SD to $<+2$ SD or obese ($\geq+2$ SD) [30].

Percentage adequacy of GWG

To calculate the percentage adequacy of GWG as the primary outcome of our study, we first found the total GWG for each participant by taking the difference between weight at the last follow-up during pregnancy and first trimester weights (imputed or observed). Then, we estimated the expected weight gain for each woman based on the 2009 IOM guidelines using the following formula, as used in Adu-Afarwuah et al. [31]:

Recommended GWG = expected first trimester total weight gain + {[(gestational age at the last weight measurement − $13^{6/7}$ wk (equivalent to 13.86 wk)] × recommended rate of GWG for the second and third trimester by BMI category}.

Expected first trimester weight gains by BMI and recommended rate of GWG in the second and third trimesters are summarized in Supplemental Table 2. Percentage adequacy of GWG was calculated by dividing observed GWG at the last measure by the expected GWG at the last observed weight measurement and multiplying by 100. Then, the continuous measure was categorized into 4 categories: severely inadequate (<70%); inadequate (70% to <90%); adequate (90%–125%); excessive (>125%). Cut points for adequate GWG were established based on the upper and lower limits of recommended ranges of weight gain during pregnancy (Supplemental Table 2). For example, for a woman with a normal BMI value, expected GWG by 40 wk of gestation is 12.8 kg: 2.0 kg + [(40 wk − 13 wk) × 0.4 kg/wk] = 12.8 kg. Thus weight gain between the lower (11.5 kg/12.8 kg) and upper (16 kg/12.8 kg) limits calculates to 90%–125% of the 12.8 kg expected weight gain for those with normal BMI and is deemed adequate, whereas weights outside this range are either inadequate or excessive. The cutoff for severely inadequate weight gain is proposed as 70% by our study team as a reasonable cutoff but has not been used in previous literature. Using the percentage adequacy based on these cutoffs set by the lower and upper limits allowed us to categorize GWG adequacy at any gestational age, rather than total GWG.

As a sensitivity analysis, we also calculated GWG *z*-scores using the INTERGROWTH-21st GWG standards [28] and categorized the variable into the following 5 groups: <−2 SD, −2 to <−1 SD, −1 to 1 SD, >1 to <2 SD, and ≥2 SD.

Socioeconomic and demographic variables

To assess potential confounding and look at relationships between socioeconomic or demographic factors and GWG adequacy, several additional variables were examined. A baseline wealth index was calculated using a principal component analysis with household asset ownership data (television, refrigerator, radio, sofa, and fan) [32] and recoded into quartiles. The maternal age was categorized as younger than 20, 20–24, 25–29, or ≥30 y; maternal education was categorized as 0–4, 5–7, 8–11, or ≥12 y; marriage status was dichotomized as married or unmarried; gravidity was categorized as 0, 1, 2, or ≥3; alcohol consumption was made into a binary variable for none or any during pregnancy; and prenatal supplementation group was assessed as a binary variable for MMS or placebo. Variables were chosen as potential confounders based on their theoretical relationship with GWG and diet quality, based on previous literature, and significant associations with the outcome in univariable regression models. Although malarial infection could also be a potential confounder, malaria prevalence in our sample at enrollment was very low (<2%), so we did not include this in our statistical analyses.

Statistical analysis

We limited the sample to singleton pregnancies, women who reported gestational age by last menstrual period, who had ≥one 24-h dietary recall, and whose last weight measurement was taken before 43 wk of gestation. Primary analyses of associations between diet quality and GWG adequacy were conducted using multinomial logit regression models. All models were adjusted for total energy intake because macronutrient intake is correlated with total energy intake. The models were additionally adjusted for supplementation arm from the original trial (placebo compared with multiple micronutrient supplement), to account for any potential differences in GWG outcomes due to the vitamins. Potential confounders found to be significantly associated with GWG outcomes in univariable analyses ($P <$ 0.05) were included in the final, fully adjusted models.

Substitution models for macronutrients were estimated by including the total energy intake variable along with all subgroups for each macronutrient, except the one to be substituted [33]. Estimated levels of association are reported as relative risk (RR) between exposure categories (or per unit change in continuous exposures) with 95% confidence intervals (CIs), with RRs defined as the probability of each category of GWG adequacy over the probability of the base category (adequate GWG). These RRs were obtained by exponentiating coefficients from standard multinomial logit regressions. Sensitivity analyses were performed with categorical GWG *z*-scores as the outcome.

Effect modification of the relationship between diet quality and GWG adequacy by prepregnancy BMI were tested by including interaction terms between diet quality measures and prepregnancy BMI in the multinomial logit regression models. Women in the overweight and obese categories of prepregnancy BMI were combined because of insufficient frequency of obesity. Wald tests, with P values of <0.05 were considered significant. Analyses were conducted in Stata 16.

Ethics

Approval for the original study was provided by the institutional review boards of Muhimbili University College of Health Sciences and Harvard T.H. Chan School of Public Health.

Results

GWG outcomes

The final analytical sample comprised 7577 pregnant women (participant flowchart in Supplemental Figure 1). GWG outcomes among women in the prenatal multivitamin supplementation trial are presented in Table 1 and stratified by prepregnancy BMI in Supplemental Table 3. Approximately one-half of the trial participants recorded inadequate or severely inadequate weight gain (50.9%), whereas almost one-fifth recorded excessive weight gain (18.5%). Despite mean total GWG being higher among those with underweight prepregnancy BMI, there was a higher frequency of severely inadequate and inadequate weight gain among women with underweight prepregnancy BMI than those with normal or overweight BMI.

Sociodemographic, socioeconomic, and maternal dietary characteristics

Table 1 describes the overall sociodemographic and socioeconomic characteristics of women in the trial, and Table 2 tabulates their maternal dietary factors (the primary exposure of interest). Overall, most of the 7577 women included in the

TABLE 1
Maternal sociodemographic and socioeconomic characteristics and gestational weight gain adequacy, Tanzania, 2001–2005

Maternal characteristics	Overall (*N* = 7577)
Maternal age	25.1 ± 5.1
<20	1217 (16.2)
20–24	3010 (39.9)
25–29	2030 (26.9)
≥30	1279 (17.0)
Gestational age at enrollment (wk)	21.4 ± 3.4
Gestational age at the last measurement (wk)	36.8 ± 3.7
Gravidity	1.2 ± 1.4
0	3028 (40.2)
1	2153 (28.6)
2	1208 (16.0)
≥3	1148 (15.2)
Wealth (quartiles)	
1	2960 (39.4)
2	1041 (13.8)
3	2103 (28.0)
4	1417 (18.8)
Education (y)	7.1 ± 2.8
0–4	843 (11.2)
5–7	5020 (66.6)
8–11	1291 (17.1)
≥12	388 (5.1)
Married or cohabitating	6632 (88.4)
Prepregnancy BMI category (kg/m^2)[1]	
Underweight (<18.5)	800 (10.6)
Normal weight (18.5 to <25)	4964 (65.6)
Overweight (25 to <30)	1423 (18.8)
Obese (≥30)	378 (5.0)
Maternal height (cm)	155.5 ± 6.0
Alcohol consumption (any during pregnancy)	1021 (12.6)
Supplementation group	
Placebo	3777 (50)
Multivitamins	3800 (50)
Gestational weight gain (GWG)	
Total GWG (kg)	9.8 ± 3.8
IOM % adequacy ratio of GWG	95.7 ± 43.0
Severely inadequate (<70%)	1911 (25.3)
Inadequate (70% to <90%)	1937 (25.6)
Adequate (90%–124%)	2314 (30.6)
Excessive ≥125%)	1399 (18.5)
GWG *z*-score	−0.62 ± 1.1
<−2 SD	628 (8.3)
−2 to < −1 SD	1709 (22.6)
−1 to 1 SD	4884 (64.6)
>1 to <2 SD	306 (4.1)
≥2 SD	32 (0.42)

Data are mean ± standard deviation or *n* (%).Missing values by variable: age, 41; gravidity, 40; wealth, 56; education, 35; married, 61; prepregnancy BMI, 12; alcohol, 37; dietary data, 551.

[1] For those younger than 20 y at enrollment (adolescents), WHO growth references were used to calculate BMI-for-age *z*-scores and classify women with <−2 SD as underweight, −2 SD to <1 SD as normal weight, 1 SD to <+2 SD or obese (≥+2 SD).

analysis were younger than 24 y, primigravid, married or cohabitating, had ≤7 y of education, and had normal prepregnancy BMI. The maternal dietary quality was low overall. Macronutrient intake was inadequate for protein, with 56% of the sample consuming protein below AMDR. Carbohydrate intake was excessive, with 58% of the sample consuming carbohydrates above the AMDR. Approximately 30% of participants consumed fat either below or above the AMDR. Mean (±SD) dietary diversity was 2.86 ± 0.75 of a potential 10 food groups consumed over the previous 24-h period, and most women had dietary diversity scores <4 (93.3%). All women had GDQS values that classified them as having poor diets (scores of <15); the mean GDQS was 2.4 ± 1.80 of a potential 49, with a range of 0–13, and the 99th percentile of 6.1. Hence, analyses using the preset categories for GDQS (poor, medium, and good) were impossible, and instead, we divided the sample into GDQS terciles for further analyses. The mean score in tercile 1 was 0.64 ± 0.56, in tercile 2 was 2.12 ± 0.32, and in tercile 3 was 4.37 ± 1.4. Similarly, analyses with the GDQS subscales, GDQS+ and GDQS−, to examine the relative importance of healthy compared with unhealthy foods, was not possible in this sample owing to extremely small range of values for each.

TABLE 2
Maternal dietary characteristics of women in a prenatal multivitamin supplementation trial by gestational weight gain adequacy level, Tanzania, 2001–2005

Maternal dietary factors	Overall (*N* = 7577)
Total energy intake (kcal/d)	2209.9 ± 609.7
Percentage energy from carbohydrates	66.6 ± 10.2
Percentage energy from fat	27.6 ± 7.3
Percentage energy from protein	10.3 ± 2.7
AMDR for carbohydrates	
Below	178 (2.5)
Within	2760 (39.3)
Above	4075 (58.1)
AMDR for fat	
Below	994 (14.2)
Within	5033 (71.8)
Above	986 (14.1)
AMDR for protein	
Below	3912 (55.8)
Within	3100 (44.2)
Above	1 (0.01)
Dietary diversity	2.86 ± 0.75
<2	147 (2.1)
2 to <3	3676 (52.3)
3 to <4	2734 (38.9)
≥4	469 (6.7)
GDQS (0–49)	2.4 ± 1.8
Poor (<15)	7006 (100.0)
Medium (15–23)	0 (0)
Good (>23)	0 (0)
GDQS terciles	
Lowest	2249 (33.3)
Middle	2259 (33.3)
Highest	2245 (33.3)
GDQS+ (0–32)	2.7 ± 1.8
GDQS− (0–17)	0.11 ± 0.4

Data are mean ± standard deviation or n (%).
AMDR, acceptable macronutrient distribution range; GDQS, Global Diet Quality Score.

Associations between sociodemographic and socioeconomic characteristics and GWG

Associations between the baseline sociodemographic and socioeconomic characteristics and GWG adequacy are presented in Table 3. In multivariate models including all socioeconomic variables presented, prepregnancy BMI, education level, maternal height, and wealth quartile were all significantly associated with GWG adequacy. Compared with participants with a normal prepregnancy BMI, those in the underweight

TABLE 3
Association between baseline sociodemographic, socioeconomic, and anthropometric characteristics and gestational weight gain, Tanzania, 2001–2005 (N = 7025)

	Severely inadequate weight gain		Inadequate weight gain		Excessive weight gain	
	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)
Prepregnancy BMI category (kg/m^2)[1]						
Underweight (<18.5)	1.38* (1.05, 1.83)	1.51*** (1.13, 2.01)	1.51** (1.14, 1.99)	1.57*** (1.18, 2.09)	0.47** (0.28, 0.80)	0.46*** (0.27, 0.79)
Normal weight (18.5 to <25)	Reference	Reference	Reference	Reference	Reference	Reference
Overweight (25 to <30)	0.64** (0.49, 0.83)	0.67*** (0.51, 0.88)	0.50*** (0.37, 0.66)	0.48*** (0.36, 0.65)	6.45*** (5.10, 8.16)	6.73*** (5.28, 8.59)
Obese (≥30)	0.97 (0.55, 1.73)	0.94 (0.52, 1.72)	0.53 (0.26, 1.09)	0.50* (0.24, 1.02)	18.41*** (11.83, 28.65)	21.12*** (13.36, 33.40)
Age category (y)						
<20	Reference	Reference	Reference	Reference	Reference	Reference
20 to <25	0.88 (0.69, 1.13)	0.95 (0.73, 1.23)	1.05 (0.81, 1.35)	1.07 (0.82, 1.40)	1.27 (0.94, 1.73)	1.17 (0.82, 1.66)
25 to <30	0.67** (0.51, 0.88)	0.78 (0.56, 1.07)	0.87 (0.66, 1.14)	0.98 (0.71, 1.35)	1.52** (1.11, 2.09)	1.13 (0.75, 1.71)
≥30	0.86 (0.64, 1.15)	0.87 (0.58, 1.30)	0.99 (0.73, 1.34)	1.10 (0.73, 1.64)	1.42* (1.00, 2.00)	0.74 (0.45, 1.24)
Education (y)						
0–4	Reference	Reference	Reference	Reference	Reference	Reference
5–7	0.72* (0.55, 0.95)	0.84 (0.63, 1.11)	0.74* (0.56, 0.98)	0.82 (0.61, 1.11)	1.17 (0.83, 1.66)	0.92 (0.65, 1.32)
8–11	0.43*** (0.31, 0.61)	0.61*** (0.42, 0.88)	0.59** (0.42, 0.82)	0.72* (0.50, 1.05)	1.34 (0.91, 1.97)	0.98 (0.64, 1.50)
≥12	0.37*** (0.22, 0.62)	0.63 (0.37, 1.09)	0.48** (0.29, 0.79)	0.70 (0.40, 1.20)	1.98** (1.22, 3.23)	1.23 (0.69, 2.20)
Height (cm)	0.96*** (0.95, 0.97)	0.96*** (0.95, 0.98)	0.97*** (0.95, 0.98)	0.97*** (0.95, 0.98)	1.00 (0.99, 1.02)	1.01 (0.99, 1.03)
Marriage status						
Married	Reference	Reference	Reference	Reference	Reference	Reference
Unmarried	0.93 (0.71, 1.22)	0.92 (0.69, 1.22)	0.83 (0.63, 1.09)	0.85 (0.64, 1.13)	0.91 (0.67, 1.22)	1.05 (0.75, 1.47)
Wealth quartile						
1	Reference	Reference	Reference	Reference	Reference	Reference
2*	0.88 (0.68, 1.15)	0.95 (0.73, 1.24)	0.9 (0.69, 1.18)	0.97 (0.74, 1.27)	1.13 (0.83, 1.53)	1.03 (0.75, 1.42)
3	0.63*** (0.51, 0.78)	0.72*** (0.58, 0.90)	0.89 (0.72, 1.10)	1.01 (0.81, 1.27)	1.33** (1.05, 1.69)	1.09 (0.83, 1.44)
4	0.51*** (0.39, 0.65)	0.67*** (0.51, 0.89)	0.62*** (0.48, 0.80)	0.78* (0.59, 1.02)	1.58** (1.22, 2.04)	1.07 (0.78, 1.47)
Gravidity						
0	Reference	Reference	Reference	Reference	Reference	Reference
1	0.95 (0.77, 1.17)	1.00 (0.79, 1.26)	1.05 (0.85, 1.30)	1.09 (0.86, 1.37)	0.94 (0.75, 1.20)	0.74* (0.55, 1.00)
2	0.84 (0.65, 1.08)	0.92 (0.67, 1.26)	0.89 (0.69, 1.15)	0.93 (0.69, 1.27)	1.17 (0.89, 1.53)	0.78 (0.54, 1.12)
≥3	1.26 (0.97, 1.64)	1.34 (0.92, 1.94)	1.19 (0.91, 1.55)	1.26 (0.87, 1.82)	1.21 (0.91, 1.61)	0.79 (0.51, 1.22)
Alcohol						
Never	Reference	Reference	Reference	Reference	Reference	Reference
Any	0.86 (0.66, 1.11)	1.06 (0.81, 1.40)	0.91 (0.70, 1.19)	1.06 (0.80, 1.39)	1.34* (1.03, 1.75)	1.02 (0.74, 1.39)

Values are risk ratios and 95% confidence intervals from multinomial regressions adjusted for total energy intake, prepregnancy BMI, maternal age, maternal education, maternal height, wealth quartile, alcohol use, and supplementation group: *$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

[1] For those younger than 20 y at enrollment (adolescents), WHO growth references were used to calculate BMI-for-age z-scores and classify women with <-2 SD as underweight, -2 SD to <1 SD as normal weight, 1 SD to $<+2$ SD or obese ($\geq+2$ SD).

category exhibited a 51% higher risk of severely inadequate weight gain (RR: 1.51; 95% CI: 1.13, 2.01), 57% higher risk of inadequate weight gain (RR: 1.57; 95% CI: 1.18, 2.09), and 54% lower risk of excessive GWG (RR: 0.46; 95% CI: 0.27, 0.79). Participants in the overweight prepregnancy BMI category were 33% less likely to have severely inadequate GWG (RR: 0.67; 95% CI: 0.51, 0.88), 52% less likely to have inadequate weight gain (RR: 0.48; 95% CI: 0.36, 0.65), and 6.73 times as likely to have excessive weight gain (RR: 6.73; 95% CI: 5.28, 8.59) compared with those with normal prepregnancy BMI. Those with obese-category prepregnancy BMIs were 21.12 times as likely to have excessive weight gain than those with normal prepregnancy BMIs (RR: 21.12; 95% CI: 13.36, 33.40). Compared with those with 0–4 y of education, those with 8–11 y had a 39% lower risk of severely inadequate weight gain (RR: 0.61; 95% CI: 0.42, 0.88). For each cm increase in maternal height, the risk of severely inadequate weight gain or inadequate weight gain was 4% (RR: 0.96; 95% CI: 0.95, 0.98) and 3% (RR: 0.97; 95% CI: 0.95, 0.98) lower, respectively. Finally, women in the top 2 wealth quartiles had a 28% lower risk of severely inadequate weight gain (RR: 0.72; 95% CI: 0.58, 0.90) and a 33% lower risk (RR: 0.67; 95% CI: 0.51, 0.89), respectively, than those in the lowest wealth quintile. Age, marriage status, gravidity, and alcohol use were not significantly associated with GWG in multivariate models.

Associations between dietary factors and GWG

Associations between diet quality indices and GWG are presented in Table 4. After adjusting for sociodemographic and socioeconomic characteristics, dietary diversity category was not statistically significantly associated with GWG adequacy. Those with GDQS scores in the second tercile had an 18% lower risk of inadequate weight gain than those in the first tercile (RR: 0.82; 95% CI: 0.70, 0.97), and those in the third tercile had a 2% (nonstatistically significant) lower risk of inadequate weight gain (RR: 0.98; 95% CI: 0.83, 1.16). Macronutrient associations with GWG are tabulated in Table 5. Increased protein intake in this sample was associated with a 6% higher risk of severely inadequate weight gain for each additional g of protein consumed (RR: 1.06; 95% CI: 1.02, 1.09), and an AMDR below the recommended proportion of one's diet from protein was associated with a 20% lower risk of severely inadequate weight gain (RR: 0.80; 95% CI: 0.67, 0.96). Substitution of carbohydrates for protein was slightly protective against severely inadequate weight gain; for each 1% increase in carbohydrates as a replacement for a 1% decrease in protein, the risk of severely inadequate weight gain decreased by 2%, adjusting for total energy intake and sociodemographic and socioeconomic factors (RR: 0.98; 95% CI: 0.96, 0.99).

Sensitivity analyses using categorized GWG *z*-scores as the outcome instead of percentage of GWG adequacy showed results consistent with main analyses (Supplemental Tables 4 and 5). Wald tests for effect modification by the prepregnancy BMI status showed significant effect modification only for the substitution of fat for protein, substitution of saturated or monounsaturated fat for polyunsaturated fat, and AMDR for fat. Stratified models for all dietary exposures are presented in Supplemental Table 6.

Discussion

Using the GDQS, an improved measure of diet quality designed and validated specifically for application across both low-income and high-income countries, we found that, in this sample of pregnant women from Dar es Salaam in the early 2000s, dietary quality was only modestly associated with GWG adequacy ratios. Overall, the diet quality was extremely poor, as was percentage of GWG adequacy. Only ~30% of the women in the sample had adequate GWG, and the mean GDQS score was 2.4 of a possible 49. This very low mean can be attributed to the heavy refined grain content of the diet, which leads to excess intake of carbohydrates and inadequate intake of protein on average, according to the AMDRs for both macronutrients. The low range of GDQS in this context highlights the limitations of the average diet in Dar es Salaam and indicates that further refinement of the tool for similar contexts may allow more informative analyses. Given the lack of heterogeneity in dietary quality and diversity scores in our sample, relationships between GDQS or MDD-W scores and GWG adequacy were modest. However, increased protein intake was associated with slightly a higher risk of inadequate GWG, and multiple socioeconomic factors were significantly related to GWG adequacy. Women with a lower prepregnancy BMI, education level, maternal height, and wealth were at higher risk of inadequate GWG, whereas those with a high prepregnancy BMI were at higher risk of excessive GWG.

TABLE 4
Association between diet quality indices and gestational weight gain, Tanzania 2001–2005 ($N = 7025$)

	Severely inadequate weight gain		Inadequate weight gain		Excessive weight gain	
	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)
Model 1: Diet diversity						
<2	Reference	Reference	Reference	Reference	Reference	Reference
2 to <3	0.67 (0.36, 1.26)	0.76 (0.40, 1.45)	0.54 (0.29, 1.00)	0.63 (0.33, 1.20)	0.88 (0.40, 1.92)	0.67 (0.31, 1.43)
3 to <4	0.66 (0.35, 1.24)	0.87 (0.45, 1.66)	0.52** (0.27, 0.97)	0.68 (0.36, 1.31)	1.03 (0.47, 2.25)	0.69 (0.32, 1.50)
≥4	0.41* (0.20, 0.84)	0.61 (0.29, 1.27)	0.52 (0.26, 1.05)	0.73 (0.36, 1.51)	1.2 (0.52, 2.78)	0.82 (0.35, 1.93)
Model 2: Global Diet Quality Score						
Tercile 1	Reference	Reference	Reference	Reference	Reference	Reference
Tercile 2	0.89 (0.76, 1.04)	0.91 (0.78, 1.07)	0.82* (0.70, 0.96)	0.82** (0.70, 0.97)	1.08 (0.91, 1.29)	1.07 (0.89, 1.30)
Tercile 3	0.86 (0.73, 1.00)	0.96 (0.81, 1.13)	0.93 (0.79, 1.09)	0.98 (0.83, 1.16)	1.05 (0.88, 1.25)	1.07 (0.88, 1.31)

Values are risk ratios and 95% confidence intervals from multinomial regressions adjusted for total energy intake, prepregnancy body mass index, maternal age, maternal education, maternal height, wealth quartile, alcohol use, and supplementation group: *$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

TABLE 5
Association between macronutrients and gestational weight gain, Tanzania, 2001–2005 ($N = 7025$)

	Severely inadequate weight gain		Inadequate weight gain		Excessive weight gain	
	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)	Energy-adjusted RR (95% CI)	Multivariable RR (95% CI)
Total energy intake (100 kcal/d)	0.98** (0.96, 0.99)	0.97*** (0.96, 0.99)	1.00 (0.99, 1.02)	1.00 (0.98, 1.01)	1.00 (0.98, 1.02)	1.02* (1.00, 1.04)
Percentage energy from carbohydrates	0.99* (0.98, 1.00)	0.99* (0.98, 1.00)	1.00 (0.99, 1.01)	0.99 (0.98, 1.00)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
Percentage energy from protein	1.04* (1.01, 1.08)	1.06** (1.02, 1.09)	1.02 (0.98, 1.05)	1.03(1.00, 1.07)	1.03 (0.99, 1.06)	1.01 (0.97, 1.05)
Percentage energy from fat	1.00 (0.99, 1.02)	1.01 (1.00, 1.02)	1.00 (0.99, 1.01)	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)	1.00 (0.99, 1.02)
Carbohydrates for protein	0.97** (0.96, 0.99)	0.98** (0.96, 0.99)	0.99 (0.97, 1.00)	0.99 (0.97, 1.00)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)
Carbohydrates for fat	0.99 (0.98, 1.01)	1.00 (0.98, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.02)
Fat for protein	0.97* (0.95, 1.00)	0.98 (0.96, 1.01)	0.98 (0.96, 1.01)	0.99 (0.97, 1.01)	1.01 (0.98, 1.03)	1.01 (0.98, 1.03)
Animal protein for plant protein	1.01 (0.97, 1.05)	1.04* (1.00, 1.08)	0.99 (0.95, 1.03)	1.02 (0.97, 1.06)	1.03 (0.99, 1.08)	1.01 (0.96, 1.06)
Saturated fat for monounsaturated fat	0.97* (0.95, 1.00)	0.98 (0.96, 1.01)	0.99 (0.97, 1.02)	1.00 (0.97, 1.02)	0.99 (0.96, 1.02)	0.99 (0.96, 1.02)
Saturated fat for polyunsaturated fat	0.97** (0.94, 0.99)	0.98 (0.96, 1.00)	0.99 (0.96, 1.01)	0.99 (0.97, 1.02)	0.99 (0.97, 1.02)	0.99 (0.96, 1.02)
Monounsaturated fat for polyunsaturated fat	0.94 (0.87, 1.01)	0.98 (0.91, 1.06)	0.94 (0.88, 1.02)	0.98 (0.91, 1.06)	1.06 (0.99, 1.15)	1.04 (0.95, 1.13)
AMDR for carbohydrates						
Below	1.21 (0.65, 2.25)	1.34 (0.71, 2.55)	1.62 (0.91, 2.90)	1.83 (1.00, 3.36)	1.46 (0.78, 2.73)	1.11 (0.56, 2.21)
Within	Reference	Reference	Reference	Reference	Reference	Reference
Above	0.88 (0.73, 1.06)	0.87 (0.72, 1.05)	0.94 (0.80, 1.14)	0.93 (0.77, 1.13)	0.89 (0.73, 1.09)	0.93 (0.74, 1.17)
AMDR for protein						
Below	0.85 (0.72, 1.02)	0.80* (0.67, 0.96)	0.95 (0.79, 1.13)	0.87 (0.73, 1.04)	0.94 (0.77, 1.13)	1.04 (0.84, 1.30)
Within	Reference	Reference	Reference	Reference	Reference	Reference
Above	—	—	—	—	—	—
AMDR for fat						
Below	0.87 (0.67, 1.14)	0.82 (0.63, 1.08)	1.24 (0.96, 1.61)	1.19 (0.91, 1.56)	0.86 (0.64, 1.16)	0.87 (0.63, 1.20)
Within	Reference	Reference	Reference	Reference	Reference	Reference
Above	1.07 (0.82, 1.38)	1.14 (0.87, 1.50)	1.16 (0.90, 1.50)	1.22 (0.94, 1.60)	1.17 (0.88, 1.55)	1.10 (0.80, 1.52)

Values are risk ratios and 95% confidence intervals from multinomial regressions adjusted for total energy intake, prepregnancy body mass index, maternal age, maternal education, maternal height, wealth quartile, alcohol use, and supplementation group: *$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
AMDR for protein above recommendation had too few values to produce reliable estimates.
AMDR, acceptable macronutrient distribution range.

These results are not entirely consistent with results of multiple previous studies that have found significant associations between other measures of dietary quality and GWG. Regarding overall diet quality, a meta-analysis of data from several low-income and high-income countries revealed significant associations between healthy diets and higher (improved) GWG [34]. In particular, in Tanzania, higher dietary quality scores on the PDQS, an earlier version of the GDQS not validated for use in LMICs, was associated with a lower risk of inappropriate GWG [21]. In addition to the PDQS not being validated for use in LMICs, the methods used for assessing mixed dishes in this study did not allow for precise calculations of diet quality because they assigned the category only to the primary component of the dish [21]. In this study, we calculated the overall diet quality more precisely, by separating mixed dishes into each of their component parts and assigning proportions of the mixed dishes to separate food categories. In other LMIC contexts, the DQI, which awards points for food variety, protein variety, micronutrient adequacy, a balanced macronutrient ratio, and moderation of saturated fat, cholesterol, and sodium, was associated with excessive weight gain in Brazil [16] and higher scores on the same index were associated with improved weight gain (higher GWG) in Indonesia [17]. In Mexico, better dietary quality scores on the MDQS during pregnancy were associated with a lower risk of both inadequate and excessive GWG [18]. In addition, women exposed to intensified nutrition interventions during their antenatal care visits in India, which improved intake of fruits and vegetables, had slightly higher GWG than those who did not have access to the nutrition intervention and whose diets were, therefore, presumed to be of a lower quality [19].

The limited variability in dietary quality in our sample, with most women consuming low-quality diets is notable, and a potential reason we do not observe the expected relationships between diet quality and GWG adequacy. Most scores in the sample (99%) fell below 6.1. Thus, the ranges within each tercile are relatively narrow, and the means by tercile are relatively close together. There is likely a little functional difference between the scores in the first and third terciles, and these small differences are not sufficiently explanatory of variance in GWG adequacy.

Nevertheless, relationships between macronutrient consumption and GWG adequacy in our sample provide additional insight. We found that increased protein intake was associated with a higher risk of severely inadequate weight gain and that substitution of fat or carbohydrates for protein was protective against severely inadequate weight gain. Substitution of fat for protein was subject to effect modification by the prepregnancy BMI status because significant protective effects against severely inadequate weight gain occurred only among those with a normal prepregnancy BMI. These results are evidently consistent with previous findings using the same data set to investigate the relationship between macronutrient intake and rate of GWG, in which the authors found that weight gain would decrease by 72 g/mo if 5% of energy from fat was substituted by proteins and by 70 g/mo if 5% energy from carbohydrates was substituted by proteins [12]. This relationship between increased protein intake and a higher risk of severely inadequate weight gain may be context specific. For example, it has been demonstrated in a study from the United States that low protein intake is associated with inadequate GWG [35]. A potential explanation for the protective effects of higher fat and carbohydrate content against inadequate GWG in the context of women in Dar es Salaam is that energy requirements may be greater owing to gender norms around domestic labor, leading to increased physical activity and exertion. A meta-analysis on data from multiple high-income and low-income countries showed that diets with high energy intake are associated with higher GWG [36]; Although this could lead to excessive weight gain in some contexts, it may protect against inadequate weight gain in contexts where physical activity demands are high. In Dar es Salaam, diets are heavy on carbohydrates, which are mostly made up of refined grains that score low on the GDQS but may be beneficial to achieving adequate GWG in this context.

Socioeconomic and nutritional status factors are revealed as more important predictors of GWG adequacy than diet quality in this sample because there is more variation in these factors. In addition, the specific socioeconomic and nutritional status factors related to GWG adequacy are factors indicative of cumulative effects of prepregnancy environment on GWG. For example, maternal height is likely related to the mothers' own growth during her infancy and childhood [7], and wealth and education are both indicators of general socioeconomic well-being and environment. The strong correlation between prepregnancy BMIs and GWG adequacy further supports the idea that the general living and environmental conditions of women who have low levels of wealth and education may not be conducive to optimal weight gain, regardless of dietary quality. Of note, the relationship between having obese-category prepregnancy BMIs and excessive weight gain has an especially large magnitude. Although we recognize that there may be unmeasured confounding of this relationship, recommended weight gain is much lower for those with obese-category prepregnancy BMIs than those with normal prepregnancy BMIs, thus the demonstrated association also points to the importance of tailored weight gain communication by the prepregnancy BMI status.

The use of the GDQS to indicate dietary quality in this study advances previous work on GWG in LMIC settings. Additional strengths include our large sample size, and thus statistical power to detect relatively small differences in percent GWG adequacy by dietary quality exposure category, and the repeated 24-h recalls, which strengthen the dietary data, allowing for means for each participant using data collected at several time points. However, we note several limitations to consider in interpretation of our results. Diets have likely evolved since the early 2000s; however, although prevalence of inadequate diets may have changed over the years, the strength and direction of associations should persist. Regardless of the age of the data set, the results provide valuable insight into the relative importance of dietary quality in relation to underlying sociodemographic factors and socioeconomic environment, including the importance of using context-specific measures and indicators for dietary quality. Similar methods to the ones used in this article should be used on updated data sets, to increase the external validity and generalizability of the findings. Second, we did not measure psychosocial factors in this study, which may confound the relationship between dietary quality and GWG. Stress and depressive symptoms have been shown to be positively associated with consumption of refined grains and added sugars in high-income contexts [37]. However, diets in the context of Dar es Salaam are made up of mainly refined grains and sugars owing to their widespread availability and affordability. Hence, although it is possible that there are unmeasured confounders in this study because there is a relationship between psychosocial factors and diet and likely between these factors and GWG, it is unlikely to have affected our results in this context. Nevertheless, evidence on how psychosocial factors may confound the relationship between diet quality and GWG is lacking, and our results highlight the importance of future investigation in this area [38]. It would also be helpful to use data on physical activity level, which is associated with GWG [16,39], to further investigate the potential for context-specific effect modification of relationships between dietary quality and GWG by physical activity demands. In addition, given that this is a secondary analysis of a trial testing supplementation with multiple micronutrient supplements against a placebo group and the supplements have been shown to reduce the risk of inadequate GWG in this population [40], we cannot rule out that supplementation group may residually influence the results of the analysis (most likely attenuating associations between diet quality and GWG); however, we adjust for supplementation group in our analyses to minimize potential confounding. Finally, measurement errors cannot be ruled out because gestational age was estimated using the last menstrual period as opposed to the gold standard of ultrasound (as is common in LMICs), and first trimester weights were estimated.

The limited direct association between diet quality indicators and GWG adequacy in this sample does not preclude the presence of such a relationship but demonstrates the strength of socioeconomic and nutritional status factors in predicting GWG adequacy in the specific context of Dar es Salaam. Conceptually, diet is a mediator in the relationship between socioeconomic factors and GWG; thus, without diet quality in the models, we would likely see an even stronger association between socioeconomic factors and GWG. Although the direct effect of diet quality may be low in this sample, the indirect and direct effect of socioeconomic factors, which include diet, is strong. In addition, penalizing diets for consumption of unhealthy foods using the GDQS revealed the extent of poor diet quality among the women in this sample, showing the utility and importance of using this new indicator to assess diet quality and its relationships with nutrition and health outcomes.

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Data availability

Data, codebooks, and analytic code will be made available on request pending application and approval.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cdnut.2023.100041.

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