Maternal dietary diversity and dietary quality scores in relation to adverse birth outcomes in Tanzanian women

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ABSTRACT

Background: Preterm birth (PTB), small for gestational age (SGA), and low birth weight (LBW) are risk factors for morbidity and mortality among infants. High-quality maternal diets during pregnancy may protect against these adverse birth outcomes.

Objectives: The aim of this study was to prospectively examine the association of maternal dietary diversity and quality during pregnancy with birth outcomes among women in Dar es Salaam, Tanzania.

Methods: We analyzed data from 7553 HIV-negative pregnant women enrolled in a multivitamin trial at 12–27 weeks of gestation. Dietary intake was assessed using 24-h dietary recalls. Dietary diversity scores (DDS; range: 0–10) were computed as the number of food groups consumed by women, using FAO's Minimum Dietary Diversity for Women index. The Prime Diet Quality Score (PDQS; range: 0–42) assessed maternal diet quality based on consumption of 21 healthy and unhealthy food groups. Log binomial regression methods were used to assess associations of DDS and PDQS with PTB, SGA, LBW, and fetal loss.

Results: In the previous 24 h, 99.9% of all women had consumed cereal and staples, 57.9% meats, 4.7% eggs, and 0.5% nuts and seeds. Median DDS was 3.0 (IQR: 2.5–3.5). For the PDQS, all women consumed ≥4 servings/wk of green leafy vegetables and refined grains. Higher DDS was associated with lower risk of SGA (RR highest compared with lowest quintile: 0.74; 95% CI: 0.62, 0.89). Higher PDQS was associated with lower risk of PTB (RR highest compared with lowest quintile: 0.55; 95% CI: 0.46, 0.66), LBW (RR: 0.53; 95% CI: 0.40, 0.70), and fetal loss (RR: 0.53; 95% CI, 0.34, 0.82).

Conclusions: PDQS was inversely associated with PTB, LBW, and fetal loss, and DDS was inversely associated with SGA. These findings suggest that in addition to dietary diversity, diet quality should be considered as important in understanding dietary risk factors for poor birth outcomes. This trial was registered at clinicaltrials.gov as NCT00197548. *Am J Clin Nutr* 2020;112:695–706.

Keywords: dietary diversity, Minimum Dietary Diversity for Women, Prime Diet Quality Score, pregnancy outcomes, low birth weight, preterm, small for gestational age, fetal loss, Tanzania

Introduction

Global progress in child survival cannot be achieved without addressing poor birth outcomes (1–3). There were 5.4 million deaths in children aged <5 y in 2016, many (40%) in the neonatal period (4). Low birth weight (LBW) and its contributing factors, preterm birth (PTB) and intrauterine growth restriction, are key determinants of neonatal mortality (5–8). LBW and PTB affect 14.6% and 10% of births respectively, mainly in developing regions (8–10). In Tanzania, rates of PTB (15.3%), small for gestational age (SGA; 16.6%), and LBW (10.5%) births (10, 11) are high. Poor birth outcomes are risk factors for morbidity including pneumonia and mortality, and they

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Supplemental Table 1 and Supplemental Figure 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

Data described in the manuscript, code book, and analytic code will be made available upon request pending approval.

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Abbreviations used: ASF, animal-source food; DDS, dietary diversity score; IFA, iron and folic acid; LBW, low birth weight; LMICs, low- and middle-income countries; LMP, last menstrual period; MDD-W, Minimum Dietary Diversity for Women; PDQS, Prime Diet Quality Score; PTB, preterm birth; SGA, small for gestational age; VLBW, very low birth weight; VPTB, very preterm birth.

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predispose children to stunting, poor cognitive development, and obesity and adult noncommunicable diseases (5, 8, 9, 12–16). Understanding the factors that lead to poor birth outcomes is of public health importance.

Pregnancy is associated with changes in nutrient metabolism and maternal physiology to support fetal growth and maintain maternal health (17, 18). If physiologic and maternal dietary changes are inadequate to meet demands, fetal growth and development are impaired (17). Although requirements increase during pregnancy (18), in Africa, Asia, and Latin America, pregnant and nonpregnant women often have poor micronutrient intakes (19, 20). Limited evidence has been published on optimal dietary patterns during pregnancy to promote healthy birth outcomes in low- and middle-income countries (LMICs) (21).

Dietary pattern analysis is underutilized in LMICs because it requires conducting expensive consumption studies (20, 22). Diet quality indices have potential for use in LMICs given their easier collection and interpretation (20). Studies show that prenatal maternal dietary diversity may be inversely associated with LBW, PTB, and SGA (14, 23, 24). However, small samples and differences in measurement of dietary diversity make firm conclusions difficult.

FAO proposed a tool to measure dietary diversity, the Minimum Dietary Diversity for Women (MDD-W) (25, 26). The MDD-W was shown to predict micronutrient adequacy for folate, iron, and others (20, 26). The Prime Diet Quality Score (PDQS) is a food group–based dietary score developed from a modified Prime Screen Questionnaire (27) to meet the need for simple measure of diet quality that can differentiate healthy foods from unhealthy foods based on associations with chronic diseases, including cardiovascular disease (28). The PDQS has been evaluated for associations with pregnancy-related morbidities (gestational diabetes) and coronary heart disease in developed countries (29, 30). The MDD-W and the PDQS have not been evaluated for associations with birth outcomes in LMICs.

We hypothesized that high-quality maternal diets during pregnancy would protect against poor birth outcomes. The current study examined the associations of maternal prenatal dietary diversity (MDD-W) and dietary quality (PDQS) with birth outcomes in a cohort of HIV-negative pregnant women in Tanzania.

Methods

Study design and population

The parent study was a double-blind, randomized, placebo-controlled trial conducted to evaluate the effect of multivitamin supplementation on birth outcomes in Dar es Salaam, Tanzania, from August 2001 to July 2004. The study included 8428 HIV-negative pregnant women who were randomized to receive multivitamin supplementation [vitamins B-1 (thiamin), B-2 (riboflavin), B-6, niacin, B-12, C, and E] or placebo from enrollment to 6 wk postpartum (31). Participants were women aged 18–45 y who were between 12 and 27 weeks of gestation at enrollment and intended to stay in the city for 1 y after delivery. All women received standard of care including iron (60 mg of elemental iron) and folic acid (0.25 mg) supplementation and malaria prophylaxis (Fansidar) according to then current Tanzanian national guidelines (31). The parent study and its main findings are described elsewhere (31).

Study procedures and follow-up

Study participants were recruited from 9 antenatal clinics in Dar es Salaam. Gestational age at enrollment was established based on menstrual history. Consenting, eligible pregnant women received pre-test counselling and were screened for HIV and syphilis. Trained research nurses administered a baseline questionnaire that included sociodemographic and obstetrical history for recruited women. Women attended monthly follow-up visits up to 6 mo postpartum as per the trial protocol. In monthly follow-up visits, questionnaires were administered to evaluate interim medical problems. Research midwives attended to the women at delivery and measured birth weights of infants to the nearest 10 g and birth length to the nearest 0.1 cm (31). Gestational age was ascertained at the time of determining eligibility for study participation. Study women were asked by trained research nurses to provide a precise date for the first day of their last menstrual period (LMP). Recall of this date was aided by the use of a calendar and locally relevant dates in the woman's surroundings.

Dietary diversity and quality

The primary exposures of interest, maternal dietary diversity [dietary diversity score (DDS)] and maternal dietary quality (PDQS) during pregnancy, were assessed using 24-h dietary recall questionnaires administered to mothers at recruitment and at subsequent monthly follow-up visits during pregnancy. Women were asked to recall food consumed in the previous 24 h, from when they woke up the previous day to the time they went to bed. Common household utensils were used to estimate portion sizes.

DDS

Dietary diversity food groups were computed based on guidance provided by FAO for the MDD-W (25). The MDD-W was proposed for adoption in low- and middle-income regions based on evidence that it was positively correlated with mean nutrient adequacy for 11 micronutrients (vitamin A, thiamin, riboflavin, niacin, vitamin B-6, folate, vitamin B-12, vitamin C, calcium, iron, and zinc) (20, 25). As proposed by FAO, 10 food groups were computed: starchy staples; beans and peas; nuts and seeds; dairy; flesh foods (meat, fish); eggs; vitamin A–rich dark green vegetables; other vitamin A–rich fruits and vegetables; other vegetables; and other fruits (25). For mixed dishes, we categorized foods based on their main components based on the Tanzania food composition tables to minimize misclassification (32). We included fruit juices under other fruits, and we included maize and kidney bean dishes under starchy staples and beans and peas groups. If a food was eaten $\geq$1 times in the previous 24 h, it was considered to contribute to the food group. No minimum weight restriction was considered for classifying foods into food groups.

The criterion for meeting minimum dietary diversity (MDD-W) was the consumption of food from $\geq$5 of the 10 food groups. We anticipated that in our study there would be a low proportion of women meeting that level of diversity, and we used quintiles of DDS as the main study exposure to examine the dose–response relationship with pregnancy outcomes. Scores for DDS were

TABLE 1 Baseline sociodemographic characteristics by dietary diversity and diet quality quintiles in HIV-negative women in Tanzania[1]

	DDS[2]		PDQS	
Characteristics	Quintile 1 $n = 1550$	Quintile 5 $n = 1448$	Quintile 1 $n = 1732$	Quintile 5 $n = 1390$
Study characteristics				
Multivitamin regimen				
Placebo	781 (50.4)	698 (48.2)	852 (49.3)	664 (47.8)
Multivitamin	769 (49.6)	750 (51.8)	878 (50.7)	726 (52.2)
Gestational age at recruitment, wk	21.5 ± 3.4	21.4 ± 3.4***	22.0 ± 3.3	20.6 ± 3.4***
Maternal demographic characteristics				
Maternal age				
Mean ± SD, y	24.7 ± 4.9	25.9 ± 5.1***	25.0 ± 5.0	25.8 ± 5.1***
15 to <25 y	924 (59.9)	721 (48.2)***	998 (57.9)	690 (50.0)**
25 to <35 y	558 (36.2)	667 (46.4)***	640 (37.1)	616 (44.6)**
≥35 y	61 (4.0)	79 (5.5)***	87 (5.0)	74 (5.4)**
Education achievement				
Primary school or none	1329 (86.0)	942 (65.4)***	1391 (80.6)	959 (69.4)***
Secondary school	183 (11.8)	332 (23.1)***	267 (15.5)	307 (22.3)***
Tertiary education	34 (2.2)	166 (11.5)***	67 (3.9)	115 (8.3)***
Marital status				
Married	1063 (68.6)	954 (65.9)	1160 (67.0)	942 (67.8)
Parity				
No children	640 (41.4)	695 (48.3)*	772 (44.8)	598 (43.3)
1 child	469 (30.3)	381 (26.5)*	501 (29.1)	401 (29.0)
≥2 children	437 (28.3)	363 (25.2)*	451 (26.2)	382 (27.7)
Wealth index, Filmer–Pritchett wealth score				
Above median	880 (56.8)	498 (34.4)***	837 (48.3)	558 (40.1)***
Food expenditure per person per day[3]				
Low (<500 shillings)	632 (40.8)	483 (33.4)***	621 (35.9)	527 (37.9)
Maternal health and nutrition characteristics				
BMI				
Mean ± SD, kg/m^2	24.5 ± 3.9	24.8 ± 4.0*	24.6 ± 3.9	24.7 ± 4.0
Underweight (BMI: <18.5)	33 (2.4)	21 (1.6)*	26 (1.7)	22 (1.8)
Normal weight (BMI: 18.5–24.99)	826 (60.6)	722 (56.2)*	898 (60.2)	702 (58.0)
Overweight (BMI: 25–29.99)	380 (27.9)	398 (31.0)*	3431 (28.9)	360 (29.8)
Obese (BMI: ≥30)	124 (9.1)	143 (11.1)*	137 (9.2)	126 (10.4)
Hemoglobin at baseline				
Mean ± SD, g/dL	10.2 ± 1.6	10.3 ± 1.5*	10.2 ± 1.5	10.4 ± 1.5*
Severe anemia (<8.5 g/dL)	174 (13.1)	124 (10.1)*	186 (12.3)	110 (9.3)*
Moderate anemia (8.5–10.9 g/dL)	726 (54.8)	673 (54.7)*	849 (56.3)	639 (53.8)*
Normal (≥11 g/dL)	424 (32.0)	34 (35.3)*	472 (31.3)	439 (37.0)*
Other characteristics				
Energy intake				
Median (IQR), kcal	2029 (1436-2722)	2396 (1755-3019)***	2123 (1473-2831)	2262 (1648-2875)**
Season of maternal dietary intake				
Dry (December–March)	630 (40.7)	577 (39.9)	647 (27.4)	619 (44.5)***
Long rains (April–May)	133 (8.6)	120 (8.3)	153 (8.8)	88 (6.3)***
Harvest (June–September)	546 (35.2)	507 (35.0)	682 (39.4)	435 (31.3)***
Short rains (October–November)	241 (15.6)	244 (16.9)	250 (14.4)	248 (17.8)***
Sex of child				
Female	766 (49.4)	712 (49.2)	848 (49.0)	691 (49.7)

[1]Values are *n* (%) for categorical variables and means ± SDs for continuous variables. Chi-square *P* values are reported for categorical/binary variables, and the Wilcoxon's signed-rank test values are reported for continuous variables. Significance levels reported compare all quintiles, $^*P < 0.05$, $^{**}P<0.01$, $^{***}P < 0.001$. DDS, Dietary Diversity Score; PDQS, Prime Diet Quality Score.

[2]DDS for women is based on the mean of repeated 24-h dietary recalls. Quintiles were calculated.

[3]Tanzanian shillings (US dollar = ∼1250 shillings at the time of the study).

computed as the total number of food groups consumed in the previous 24 h. All available measures of dietary intake during pregnancy were used, with mean dietary diversity computed as the arithmetic mean of all available measures of prenatal DDS for each woman.

PDQS

Foods consumed by women during pregnancy in each 24-h recall were classified into 21 food groups for the PDQS. Foods were classified as healthy [dark green leafy vegetables, other vitamin A–rich vegetables (including carrots), cruciferous

vegetables, other vegetables, whole citrus fruits, other fruits, fish, poultry, legumes, nuts, low-fat dairy, whole grains, eggs, and liquid vegetable oils] or unhealthy (red meat, processed meats, refined grains and baked goods, sugar-sweetened beverages, desserts and ice cream, fried foods obtained away from home, and potatoes) based on criteria determined by previous studies (29, 30). We modified the score with the inclusion of red and orange fruits and vegetables as the "other vitamin A–rich fruits and vegetables" category, in place of carrots only as a food group. In our study location, although consumption of carrots is low, other fruits and vegetables are local sources of vitamin A.

The number of servings of food groups was calculated for each day of dietary recall. We considered each occasion of consumption of a food group as a serving. We then computed the mean number of servings over the available recall days for each woman. The mean number of servings for each food group was then multiplied by 7 to standardize to the number of servings per week, from which points for each food group could be assigned based on whether the food was categorized as healthy or unhealthy. Points were assigned for consumption of healthy food groups as follows: 0–1 serving/wk, 0 points; 2–3 servings/wk, 1 point; and ≥4 servings/wk, 2 points. Scoring for unhealthy food groups was assigned as follows: 0–1 serving/wk, 2 points; 2–3 servings/wk, 1 point; and ≥4 servings/wk, 0 points (30). Points for each food group were then summed to give an overall score. Consumption of low-fat dairy and processed meats was not recorded in the parent study, but it is believed to be low in Tanzania (33). Refined grains were defined based on classification from previous studies (29, 30). In the analysis, millet- and sorghum-based foods were categorized as whole grains, and maize flour–based products were classified as refined grains.

Study outcomes

After recruitment, participants were tracked closely with monthly antenatal visits by study staff to ascertain study outcomes, including fetal loss. The primary study outcomes were PTB (<37 weeks of gestation), SGA (determined using the INTERGROWTH standards of birth weight <10th percentile for gestational age and sex) (34), LBW (defined as birth weight <2500 g), and fetal loss (defined as spontaneous abortion or stillbirth). Fetuses who died in utero were considered fetal losses. If the loss happened ≥28 weeks of gestational age, it was considered a stillbirth. If earlier, it was considered a spontaneous abortion. The secondary outcomes of the study were very low birth weight (VLBW; birth weight <2000 g), very preterm birth (VPTB; <32 weeks of gestation), and severe SGA (defined as birth weight <3rd percentile for gestational age and sex based on INTERGROWTH standards) (34).

Ethics

Approval for the study was provided by the institutional review boards of Muhimbili University College of Health Sciences and Harvard TH Chan School of Public Health. Written informed consent was obtained from all enrolled women.

Statistical analysis

The analysis was restricted to women with singleton births. Extreme diet measures for women, defined as total daily caloric intake <500 kcal or >4000 kcal or total daily protein intake <7 g or >200 g, were excluded from the analysis. We computed Spearman correlations between continuous DDS and PDQS scores to evaluate their association. DDS and PDQS quintiles were calculated based on all available dietary data. We used quintiles of the DDS and PDQS because we determined that these would better discriminate women with low diet quality from those with relatively higher quality diets. The use of quintiles of DDS and PDQS provides an opportunity to examine dose–response. Socioeconomic and demographic characteristics of the study population were evaluated by comparing quintiles 1 and 5 of diet scores, using chi-square (categorical variables) and the Wilcoxon test (continuous variables). Consumption of DDS food groups by quintiles of DDS was compared using chi-square tests. Consumption of PDQS food groups by study women was also described. Log binomial regression (35) was used to evaluate the associations of DDS and PDQS with the primary and secondary outcomes.

Potential confounders for each outcome were selected based on associations with the outcome in univariate regression models at $P < 0.20$. Confounders considered included maternal characteristics [age, marital status, education, history of fetal loss, parity, maternal height or maternal shortness (height <145 cm)], household income and wealth characteristics [food expenditure <500 Tanzanian shillings/person/d (US dollar estimated at ∼1250 shillings)], wealth index developed using the Filmer–Pritchett wealth methodology (households above/below the median) (36), and season [dry (December–March), long rains (April–May), harvest (June–September), and short rains (October–November)] (37). All models adjusted for multivitamin group assignment (placebo/multivitamin) and child sex (male/female). Final models adjusted for energy intake using restricted cubic splines, maternal BMI [in kg/m^2; underweight (BMI <18.5), normal weight (BMI: 18.5–24.99), overweight (BMI: 25–29.99), obese (BMI ≥30)], and anemia [severe (hemoglobin <8.5 g/dL), moderate (hemoglobin: 8.5–10.9 g/dL), none (hemoglobin ≥11 g/dL)] at baseline. The missing indicator method was used to adjust for missing confounder data (38).

Tests for trend were conducted for multivariate models using median scores for DDS and PDQS quintiles. Secondary analyses were conducted with a binary indicator for MDD-W, defined as the consumption of food from ≥5 of the 10 food groups in the previous 24 h (25). At this predetermined cutoff, women are most likely to meet their micronutrient intake based on validation studies (20, 25).

Finally, effect modification by treatment regimen was tested in fully adjusted models. The likelihood ratio test based on a significance level of $P < 0.05$ was used to evaluate effect modification. Statistical analysis was conducted using SAS software (version 9.4; SAS Institute).

Results

A total of 7553 pregnant women with singleton births and at least one 24-h dietary recall during pregnancy were included in the analysis (**Supplemental Figure 1**). The analysis excluded

TABLE 2 Food groups consumed at all times by HIV-negative pregnant women in Tanzania by DDS quintiles[1]

Food group[2]	Food list	Overall	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
			$n = 3937$	$n = 4250$	$n = 4244$	$n = 4162$	$n = 3673$
Starchy staples	Traditional doughnut (mandazi), maize, bread, cassava, chapati, Irish potato, pilau, plantain, sweet potato, taro, ugali	20,232 (99.9)	3911 (99.6)	4250 (100)	4244 (100)	4157 (99.9)	3670 (99.9)***
Beans and peas	Bambara nuts, beans, mung bean (choroko), chickpea (dengu), cowpea (kunde), pigeon peas (mbaazi), peas	8224 (40.6)	1176 (30.0)	1663 (39.1)	1747 (41.2)	1851 (44.5)	1787 (48.6)***
Nuts and seeds	Groundnuts	103 (0.5)	3 (0.1)	7 (0.2)	11 (0.3)	26 (0.6)	56 (1.5)***
Dairy	Cow milk	1240 (6.1)	40 (1.0)	118 (2.8)	183 (4.3)	324 (7.7)	575 (15.7)***
Flesh foods (meats)	Beef, chicken, fish, goat, liver, pork	11734 (57.9)	1721 (43.8)	2231 (52.5)	2450 (57.7)	27147 (66.0)	2585 (70.4)***
Eggs	Eggs	943 (4.7)	49 (1.3)	91 (2.1)	169 (4.0)	213 (5.1)	421 (11.5)***
Vitamin A–rich dark green vegetables	Cassava leaves (kisamvu), cowpea leaves (kunde leaves), pumpkin leaves, spinach, sweet potato leaves	8800 (43.4)	996 (25.4)	1541 (36.3)	2033 (47.9)	2035 (48.9)	2195 (59.8) ***
Other vitamin A–rich fruits and vegetables	Peppers (fresh hoho), mango, papaya, pumpkin, passion fruit, passion fruit juice	2806 (13.9)	83 (2.1)	216 (5.1)	451 (10.6)	777 (18.7)	1279 (34.8)***
Other vegetables	Bitter tomato, Chinese cabbage, cabbage, eggplant, hare lettuce (mchunga), okra, tomato, green maize	1672 (8.3)	100 (2.6)	235 (5.5)	344 (8.1)	388 (9.3)	605 (16.5)***
Other fruits	Avocado, baobab, cucumber, guava jackfruit, lemon, lime, orange, peach, pineapple, plum, banana, tangerine, watermelon, other fruit juices	5040 (24.9)	182 (4.6)	581 (13.7)	916 (21.6)	1343 (32.3)	2018 (54.9)***
DDS[3]	Median, IQR	3.0 (2.5-3.5)	2.0 (2.0–2.3)	2.5 (2.5–2.7)	3.0(3.0–3.0)	3.5(3.3–3.5)	4.0(4.0–4.5) ***

[1]Values are *n* (%) unless otherwise noted. *n* = total number of times that consumption of a food group is reported by study women in all study visits. Significance is based on Fisher's exact test and Wald *t* statistics for continuous variables. Chi-square *P* values are reported for categorical/binary variables. Significance tests compare all quintiles within a food group, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. DDS, Dietary Diversity Score.

[2]African doughnuts are categorized under starchy staples; maize and kidney bean dishes are categorized under starchy staples and beans and peas respectively, and banana with meat and coconut milk, as well as rice and meat pillau are categorized under the starchy staples and meats groups. Passion fruit is categorized under other vitamin A-rich fruits and vegetables.

[3]Dietary diversity for women based on multiple 24-h dietary recalls.

TABLE 3 PDQS food groups consumed by HIV-negative pregnant women in Tanzania[1]

Healthy foods Servings and points	0–1 serving/wk (0 points)	2–3 servings/wk (1 point)	≥4 servings/wk (2 points)
Cruciferous vegetables	6592 (86.4)	761 (10.1)	265 (3.5)
Dark leafy green vegetables	2 (0.0)	2 (0.0)	7549 (100)
Eggs	6661 (88.2)	707 (9.4)	185 (2.5)
Fish	5237 (69.3)	1511 (20.0)	805 (10.7)
Legumes	2687 (35.6)	1754 (23.2)	3112 (41.2)
Liquid vegetable oils	7519 (99.6)	32 (0.42)	2 (0.03)
Low-fat dairy	7553 (100)	0 (0)	0 (0)
Nuts	7453 (98.7)	87 (1.1)	13 (0.2)
Other vegetables	1397 (18.5)	1272 (16.8)	4885 (64.7)
Other vitamin A–rich vegetables (including carrots)	2625 (34.8)	1746 (23.1)	2625 (34.8)
Other whole fruits	2368 (31.4)	2043 (27.1)	3142 (41.6)
Poultry	5997 (79.4)	1109 (14.7)	447 (5.9)
Whole citrus fruits	6661 (88.2)	707 (9.4)	185 (2.5)
Whole grains	6888 (91.2)	515 (6.8)	150 (2.0)
Unhealthy foods			
Servings and points	0–1 serving/wk (2 points)	2–3 servings/wk (1 point)	≥4 servings/wk (0 points)
Desserts and ice cream	4588 (60.7)	1992 (26.4)	973 (12.9)
Fried foods obtained away from home	7338 (97.2)	189 (2.5)	26 (0.3)
Potatoes	7453 (98.7)	87 (1.1)	13 (0.2)
Processed meat	7553 (100)	0 (0)	0 (0)
Red meats	4149 (54.9)	1744 (23.1)	1660 (22.0)
Refined grains and baked goods	15 (0.2)	13 (0.2)	7525 (99.6)
Sugar-sweetened beverages	5920 (78.4)	1132 (15.0)	501 (6.6)

[1] Values are *n* (%). PDQS, Prime Diet Quality Score.

133 women with extreme dietary intake (total daily caloric intake <500 kcal or >4000 kcal or total daily protein intake <7 g or >200 g).

The mean ± SD gestational age at recruitment into the study was 20.8 ± 3.5 wk. LMP was assessed at the first visit, which occurred for most women before 22 weeks of gestation. Mean ± SD gestational age at the first measure of women's diets was 28.8 ± 3.8 wk. Although on average the first dietary assessment was done at 28.8 wk, diet was always associated temporally prior to the occurrence of any birth outcome, including fetal loss (miscarriage or stillbirth). Mean ± SD gestational age at birth in the study was 39.6 ± 3.0 wk.

Diet was assessed in women up to 7 times during pregnancy. In 6293 women, diet was measured a second time, 3883 women had diet measured on 3 occasions, and 1499 women had 4 diet measurements. Dietary diversity was very low for study participants. The median DDS during pregnancy was 3.0 (IQR: 2.5–3.5). Only 213 (2.8%) of the women assessed had a mean DDS of ≥5, the FAO definition of minimum dietary diversity. PQDS scores for women ranged from 10 to 28, with a median score of 19 (IQR: 17–20). The Spearman correlation between the DDS and the PDQS was 0.36 ($P < 0.001$).

Table 1 describes the baseline characteristics of the study population. The distribution of baseline characteristics was similar for DDS and PDQS, comparing women in quintile 1 with those in quintile 5. Women in quintile 5 of both indices were older and more educated, consumed more calories, and had lower prevalence of anemia compared with women in the lowest quintile for each respective index (Table 1). For DDS, women with the most diverse diets had greater food expenditure per day and higher prevalence of BMI between 25 and 30 and BMI ≥30. There were no significant differences in assignment to multivitamins or placebo within the main trial in either score.

Table 2 shows food groups consumed by pregnant women in the previous 24 h at all prenatal measurements. In the previous 24 h, 99.9% of women reported consuming grains, roots, and tubers; 57.9% reported consuming meats; 4.7% reported consuming eggs; and 0.5% reported consuming nuts and seeds. Consumption of meats ranged from 43.8% in the lowest quintile of DDS to 70.4% in the highest quintile; consumption of other fruit ranged from 4.6% to 54.9% in the same groups.

Table 3 shows the consumption of PDQS food groups by women in the study. Almost all women consumed ≥4 servings of dark green leafy green vegetables and 64.7% other vegetables per week. However, other healthy foods, including nuts, whole grains, citrus fruits, and eggs, were consumed infrequently by women (Table 3). Refined grains (99.6%) were the most commonly consumed unhealthy food group. Consumption of ≥4 servings of red meats was higher in women in the lowest quintile compared with women in the highest quintile of the PDQS (36.7% compared with 12.7%, respectively). Consumption of legumes was highest in quintile 5 compared with the lowest quintile (75.5% compared with 8.3%, respectively) (results not shown).

PBT and VPTB

There were 1152 cases (15.3%) of PTB and 112 cases (1.5%) of VPTB in the study. In multivariate analysis, there were no significant associations between the DDS and risk of PTB

TABLE 4 Association of DDS with birth outcomes in HIV-negative women in Tanzania[1]

Clinical outcome	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P*-trend
DDS median (IQR)	2.0 (2.0–2.3)	2.5 (2.5–2.7)	3.0 (3.0–3.0)	3.5 (3.3–3.5)	4.0 (4.0–4.5)	
Preterm birth[2] (<37 weeks of gestation)						
n	252/1550	201/1428	344/1765	149/1362	206/1448	
Univariate	Ref	0.87 (0.73, 1.03)	1.20 (1.03, 1.39)*	0.67 (0.56, 0.81)***	0.88 (0.74, 1.04)	
Multivariate, energy, BMI, and anemia adjusted[3]		0.87 (0.74, 1.04)	1.24 (1.06, 1.44)*	0.72 (0.60, 0.88)**	0.97 (0.82, 1.16)	0.22
Small for gestational age[4] (<10th percentile for gestational age/sex)						
n	245/1400	231/1284	266/1601	207/1221	171/1318	
Univariate		1.03 (0.87, 1.21)	0.95 (0.81, 1.11)	0.97 (0.82, 1.15)	0.74 (0.62, 0.89)**	
Multivariate, energy, BMI, and anemia adjusted[3]		1.01 (0.86, 1.19)	0.95 (0.81, 1.11)	0.97 (0.82, 1.15)	0.74 (0.62, 0.89)**	<0.01**
Low birth weight[5] (<2500 g)						
n	114/1458	71/1359	107/1641	71/1287	85/1373	
Univariate		0.67 (0.50, 0.89)*	0.83 (0.65, 1.08)	0.71 (0.52, 0.94)*	0.79 (0.60, 1.04)	
Multivariate, energy, BMI, and anemia adjusted[3]		0.66 (0.50, 0.88)**	0.84 (0.65, 1.08)	0.70 (0.53, 0.94)*	0.80 (0.61, 1.04)	0.11
Fetal loss[6] (spontaneous abortion, stillbirth)						
n	46/1550	34/1428	72/1765	41/1362	45/1448	
Univariate		0.80 (0.51, 1.24)	1.37 (0.96, 1.98)	1.01 (0.67, 1.53)	1.05 (0.70, 1.57)	
Multivariate, energy, BMI, and anemia adjusted[3]		0.73 (0.46, 1.15)	1.37 (0.95, 1.98)	0.90 (0.58, 1.40)	0.95 (0.62, 1.45)	0.96

[1]Values are RR (95% CI) unless otherwise noted. RR and 95% CI are for more diversified diets. Dietary diversity was assessed as quintiles of mean dietary diversity throughout pregnancy. Test for trend was conducted using median DDS for diet quintiles. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. DDS, dietary diversity score.

[2]Multivariate models for preterm birth adjust for multivitamin group assignment (placebo/multivitamin), child sex (male/female) low food expenditure (yes/no), married (yes/no), wealth index above median (yes/no), maternal age (<30, 30–39, >40 y), and maternal education (no/primary, secondary, tertiary).

[3]Energy, BMI, and anemia adjusted models adjust for BMI (<18.5, 18.5–24.99, 25.0–29.9, >30), anemia status at randomization in the main trial (none, moderate, severe), and energy using restricted cubic splines in addition to covariates controlled for in multivariate models.

[4]Multivariate models for small for gestational age adjust for multivitamin group assignment (placebo/multivitamin), low food expenditure (yes/no), wealth index above median (yes/no), maternal age (<30, 30–39, >40 y), parity (0, 1–2, ≥3 children), child sex (male/female), and maternal shortness (height <145 cm).

[5]Multivariate models for low birth weight adjust for multivitamin group assignment (placebo/multivitamin), history of fetal loss (yes/no), married (yes/no), parity (0, 1–2, ≥3children), child sex (male/female), wealth index above median(yes/no), maternal age (<30, 30–39, >40 y), and maternal shortness (height <145 cm).

[6]Multivariate models for fetal loss adjust for multivitamin group assignment (placebo/multivitamin), low food expenditure (yes/no), parity (0, 1–2, ≥3 children), history of fetal loss at first pregnancy (yes/no), married (yes/no), and maternal height.

(**Table 4**) and VPTB (**Supplemental Table 1**). Models for the PDQS showed an inverse association with PTB. In adjusted models, women in the highest quintile of PDQS had 45% lower risk of PTB (RR: 0.55; 95% CI: 0.46, 0.66) (**Table 5**) and 67% lower risk of VPTB (RR: 0.33; 95% CI: 0.17, 0.64) (Supplemental Table 1) compared with women in the lowest quintile.

SGA and severe SGA

There were 1120 cases (16.4%) of SGA and 460 cases (6.7%) of severe SGA in the study. There was a significant association between DDS and SGA. In multivariate analysis (Table 4), women with highly diversified diets (quintile 5 of DDS) during pregnancy had a 26% reduction in risk of SGA (RR: 0.74; 95% CI: 0.62, 0.89) compared with women with least diversified diets (quintile 1). The association between DDS and severe SGA trended toward significance (P-trend = 0.06) (Supplemental Table 1). There was no association between PDQS and SGA (Table 5) and severe SGA (Supplemental Table 1).

LBW

There were 448 cases (6.3%) of LBW and 96 cases (1.4%) of VLBW in the study. In multivariate analysis (Table 4), the DDS showed no association with risk of LBW. The PDQS was significantly associated with LBW in multivariate models. Women with the highest diet quality (quintile 5 of PDQS) had an RR of 0.53 (95% CI: 0.40, 0.70) of having LBW births compared with women with lowest quality diets (Table 5). Similarly, women in the highest quintile of PDQS had a lower risk of VLBW (RR: 0.49; 95% CI: 0.26, 0.92) compared with women in the lowest quintile (Supplemental Table 1).

Fetal loss

There were 238 cases (3.2%) of fetal loss in the study. DDS was not significantly associated with fetal loss (Table 4). We found an inverse association between PDQS and fetal loss comparing women in the fifth quintile (RR: 0.53; 95% CI: 0.34, 0.82) with those in the first quintile (Table 5).

We considered the possibility that the associations observed in our analysis may be due to multivitamin intake in the parent trial. However, we did not find evidence of effect modification of the associations of the DDS and PDQS with any outcome by multivitamin treatment. When we restricted the analysis to the placebo group, our findings were unchanged (results not shown). We also considered the binary exposure of MDD-W (consumption of ≥5 food groups) and found that for women meeting minimum dietary diversity, the risk of SGA was lower (RR: 0.62; 95% CI: 0.41, 0.94) compared with that for women with poor dietary diversity. No significant associations were found with LBW, PTB, and fetal loss.

Finally, the categorization of red meat and potatoes as "unhealthy" is based on their association with chronic diseases in high-income countries, and observed associations may not hold in LMICs. We conducted sensitivity analyses that *1*) excluded red meat and potatoes from the PDQS and *2*) included red meat in the PDQS as a healthy food group. Our findings were unchanged (results not shown).

Discussion

This study prospectively evaluated the relation between prenatal maternal diets and adverse birth outcomes in urban Tanzania. Women with higher quality diets, defined using the PDQS, had lower risk of PTB, LBW, and fetal loss, independent of energy intake and other maternal characteristics. Women with more diversified diets, defined by DDS, were less likely to deliver infants with intrauterine growth retardation (SGA).

Previous studies have shown similar associations. Zerfu et al. (24) found that Ethiopian women with poor diets had 4.6 times the risk of PTB and twice the risk of LBW compared with women with adequate diets. Saaka (23) found that higher maternal dietary diversity was associated with 57% lower risk of LBW in Ghana. No associations were reported with stillbirth (23, 24). The current study evaluates the MDD-W, an index validated for micronutrient adequacy, unlike measures used in previous studies (23, 24), and the PDQS, an index validated in developed country settings, for associations with birth outcomes in a LMICs setting.

The observed differences in strength of associations comparing this study to others may be partially explained by the fact that we report on an urban Tanzanian cohort, in which women may have had greater access to food, animal-source foods (ASFs), fruits, and vegetables. Zerfu et al. (24), for example, reported on a rural Ethiopian cohort, in which women may have had limited dietary intake and increased micronutrient deficiencies due to limited income, poor availability of nutritious foods and ASFs in markets, and seasonality.

DDS and PDQS associations with birth outcomes differ, and this may be explained by the fact that they measure different aspects of diet. The DDS has been validated for micronutrient adequacy and does not address other aspects of diet quality, including moderation and balance (20). The PDQS, however, negatively scores the consumption of unhealthy foods (refined grains, saturated fatty acids, and red meats) associated with overweight and obesity, insulin resistance, inflammation, and C-reactive protein concentrations (29, 30, 39, 40). Consumption of "inflammatory diets" in pregnancy has been associated with lower birth weight (40). Studies show increasing nutrition transition, purchase of processed foods, and increasing BMI in urban and rural Tanzania (41–43). Given its composition, the PDQS may be suited to determine effects of unhealthy dietary patterns and maternal inflammation on birth outcomes in this context.

The MDD-W (and DDS) may have utility in LMICs in which micronutrient deficiencies are still prevalent and birth outcomes may be partly determined by micronutrient deficiencies prior to and during pregnancy (19). Poor-quality "usual" diets and pregnancy dietary intake can result in chronic undernutrition and multiple rather than single nutrient deficiencies (14). It is important to consider the effects of these deficiencies on birth outcomes.

Maternal nutrition may influence birth outcomes through several mechanisms. Maternal nutritional status prior to and during pregnancy affects nutrient availability for transfer to

TABLE 5 Association of PDQS with birth outcomes in HIV-negative women in Tanzania[1]

Clinical outcome	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P*-trend
PDQS median (IQR)	16.0 (15.0–16.0)	18.0 (17.0–18.0)	19.0 (19.0–19.0)	20.0 (20.0–20.0)	22.0 (21.0–23.0)	
Preterm birth[2] (<37 weeks of gestation)						
n	338/1732	347/2194	133/1022	192/1215	142/1390	
Univariate	Ref	0.81 (0.71, 0.93)**	0.67 (0.55, 0.80***	0.81 (0.69, 0.95)*	0.52 (0.44, 0.63)***	
Multivariate, energy, BMI, and anemia adjusted[3]		0.81 (0.71, 0.93)**	0.66 (0.55, 0.79)***	0.82 (0.70, 0.96)*	0.55 (0.46, 0.66)***	<0.001***
Small for gestational age[4] (<10th percentile for gestational age/sex)						
n	264/1605	338/1971	149/906	187/1110	182/1232	
Univariate		1.04 (0.90, 1.21)	1.00 (0.83, 1.20)	1.02 (0.86, 1.22)	0.90 (0.76, 1.07)	
Multivariate, energy, BMI, and anemia adjusted[3]		1.04 (0.90, 1.21)	0.97 (0.81, 1.17)	1.01 (0.85, 1.19)	0.91 (0.77, 1.08)	0.26
Low birth weight[5] (<2500 g)						
n	145/1606	124/2067	56/962	58/1149	65/1334	
Univariate		0.66 (0.53, 0.84)**	0.64 (0.48, 0.87)**	0.56 (0.42, 0.75)**	0.54 (0.41, 0.77)***	
Multivariate, energy, BMI, and anemia adjusted[3]		0.66 (0.53 0.83)***	0.63 (0.47, 0.84)**	0.55 (0.41, 0.74)***	0.53 (0.40, 0.70)***	<0.001***
Fetal loss[6] (spontaneous abortion, stillbirth)						
n	68/1732	71/2194	38/1022	30/1215	31/1390	
Univariate		0.82 (0.59, 1.14)	0.95 (0.64, 1.40)	0.63 (0.41, 0.96)*	0.57 (0.37, 0.86)*	
Multivariate, energy, BMI, and anemia adjusted[3]		0.78 (0.56, 1.09)	0.86 (0.57, 1.30)	0.62 (0.40, 0.95)*	0.53 (0.34, 0.82)**	<0.01**

[1]Values are RR (95% CI) unless otherwise noted. RR and 95% CIs were estimated from binomial regression models. RR <1 indicates that the risk of the outcome is lower in women with higher quality diets. Test for trend was conducted using median PDQS scores for PDQS quintiles. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. PDQS, Prime Diet Quality Score.

[2]Multivariate models for preterm birth adjust for multivitamin group assignment (placebo/multivitamin), child sex (male/female), low food expenditure (yes/no), married (yes/no), wealth index above median (yes/no), maternal age (<30, 30–39, >40 y), and maternal education (no/primary, secondary, tertiary).

[3]Energy, BMI, and anemia adjusted models adjust for BMI (<18.5, 18.5–24.99, 25.0–29.9, >30), anemia status at randomization in the main trial (none, moderate, severe), and energy using restricted cubic splines in addition to covariates controlled for in multivariate models.

[4]Multivariate models for small for gestational age adjust for multivitamin group assignment (placebo/multivitamin), low food expenditure (yes/no), wealth index above median (yes/no), maternal age (<30, 30–39, >40 y), parity (0, 1–2, ≥3 children), child sex (male/female), and maternal shortness (height <145 cm).

[5]Multivariate models for low birth weight adjust for multivitamin group assignment (placebo/multivitamin), history of fetal loss (yes/no), married (yes/no), parity (0, 1–2, ≥3 children), child sex (male/female), wealth index above median (yes/no), maternal age (<30, 30–39, >40 y), and maternal shortness (height <145 cm).

[6]Multivariate models for fetal loss adjust for multivitamin group assignment (placebo/multivitamin), low food expenditure (yes/no), parity (0, 1–2, ≥3 children), history of fetal loss at first pregnancy (yes /no), married (yes/no), and maternal height .

the fetus; thus, it is important for in-utero growth (8, 17, 44). Protein–energy supplement studies suggest a role for energy and protein intake in preventing SGA and LBW (45). We controlled for energy intake in this study, and observed associations persisted. Diversified maternal diets and micronutrient adequacy may be important for maternal weight gain and birth weight (31, 46) and may also enhance maternal nutrition status and decrease infections and morbidity during pregnancy, affecting birth outcomes (31, 47). Non-nutritional factors, including fetal inflammation due to infection and oxidative stress, maternal stress, and epigenetic programming, also affect birth outcomes (48–51). These factors, unlike maternal dietary diversity and quality, are not easily modified. Finally, we may have observed non-significant findings for associations of DDS with a number of outcomes because in our study context dietary diversity was low and had limited variability.

This study has several strengths. We had a large population sample and measured diet at multiple times during pregnancy using the 24-h dietary recall. We used an average of repeated measures obtained from more than one 24-h recall to reflect overall diet during pregnancy. The approach of calculating mean dietary diversity has been used in other studies in which repeated measures of intake are available to reduce intra-person variation and measurement error (28, 52). This study is the first in LMICs to associate the PDQS, a simple tool to incorporate analysis of diet quality that can be easily incorporated into programs, with birth outcomes.

There were several limitations of the study. We were unable to measure quality of diets early in pregnancy, even though this may be important for fetal development, given rapid cell growth and development of immune cells and organs in the first trimester (50). However, we still observed significant associations, suggesting that second- and third-trimester diets have consequences for in-utero growth. We derived PDQS scores from 24-h recalls, and there were limited precedents in the published literature for converting these scores to equivalent scores for the FFQ, with the exception of a study conducted in Bosnia and Herzegovina (53). The validity of using the PDQS score assessed using 24-h recall is an area of active research. It is notable that the 24-h recall method is used widely in developing countries, and our findings provide support for the use of this metric for deriving PDQS in these settings. We had 1260 women with a single dietary recall, which provides a limited measure of usual intake. Single 24-h dietary recalls for nutrients and foods may introduce random within-person error in the estimation of usual diet (54). This is reasonably extended to the dietary diversity, as has been shown by Thorne-Lyman et al. (52). This is a limitation of our study and might have attenuated our findings toward the null, given that we expect misclassification resulting from such measures is non-differential with respect to the outcomes examined. Limiting our analyses to women who had more than one 24-h recall did not materially change the results (results not shown). We measured gestational age of pregnancy using LMP instead of the gold standard of ultrasonography. Estimation of LMP is prone to errors due to poor maternal recall and may lead to misclassification of birth outcomes (55). LMP has been used in low-income settings when there are no other viable options. Misclassification from its use is expected to be non-differential with respect to our exposures of interest, and this random misclassification is likely to attenuate the association between dietary intake and the outcomes rather than spuriously lead to associations. Our findings may not be generalizable to populations in which dietary patterns and determinants of birth outcomes differ from those in urban Tanzania. Associations may be stronger in populations with more prevalent micronutrient and other deficiencies in pregnant women. Study women received iron and folic acid (IFA), which could potentially attenuate the influence of maternal diets on birth outcomes. However, because IFA provided prenatally is standard of care, our findings are generalizable to settings in which this is the case.

Finally, the PDQS has not been validated in Tanzania or other low-income settings. Further research is required to better understand the applicability of the PDQS in LMICs settings.

In conclusion, low maternal dietary diversity and quality may be modifiable risk factors for adverse birth outcomes in Tanzanian mothers. PDQS, a measure of maternal diet quality, was inversely associated with PTB, LBW, and fetal loss. DDS, a measure of dietary diversity, was inversely associated with SGA. These findings suggest that in addition to dietary diversity, diet quality should be considered as important in understanding risk factors for poor birth outcomes. Further study of these scoring systems in LMICs is warranted. Intervention trials should evaluate whether increasing dietary diversity and quality can improve maternal and infant health outcomes.

The authors' responsibilities were as follows—IM: conceived the study, designed the study, analyzed the data, and drafted the manuscript; WWF: principal investigator for the parent study, conceived the study, designed the study, interpreted the data, and guided revisions of the manuscript; SI, MW, and CD: designed the study, interpreted the data, and guided revisions of the draft manuscript; EH: contributed to study design and interpretation of the data; GIM and WU: co-principal investigators for the parent study, participated in the study implementation and field supervision, interpreted the data, and guided revisions of the manuscript; and all authors: read and approved the final manuscript. The authors report no conflicts of interest. We dedicate this paper in the memory of Dr Gernard I. Msamanga and his many contributions, including to nutrition in Tanzania.

References

1. Ververs M, Antierens A, Sackl A, Staderini N, Captier V. Which anthropometric indicators identify a pregnant woman as acutely malnourished and predict adverse birth outcomes in the humanitarian context? PLoS Currents 2013 June;5.
2. Jawaid SA. The global action report on preterm birth. Pulse Int 2012;13(10).
3. Lawn JE, Kerber K, Enweronu-Laryea C, Cousens S. 3.6 million neonatal deaths—what is progressing and what is not? Semin Perinatol 2010;34(6):371–86.
4. UNICEF/WHO/World Bank. Levels and trends in child malnutrition. eSocialSciences; 2018.
5. WHO/UNICEF. Global nutrition targets 2025: low birth weight policy brief. WHO, Geneva (Switzerland); 2014.
6. UNICEF. United Nations inter-agency group for child mortality estimation: levels & trends in child mortality: report 2017. New York: UNICEF; 2017.
7. Katz J, Lee AC, Kozuki N, Lawn JE, Cousens S, Blencowe H, Ezzati M, Bhutta ZA, Marchant T, Willey BA, et al. Mortality risk in preterm and small-for-gestational-age infants in low-income and

middle-income countries: a pooled country analysis. Lancet North Am Ed 2013;382(9890):417–25.
8. Imdad A, Bhutta ZA. Nutritional management of the low birth weight/preterm infant in community settings: a perspective from the developing world. J Pediatr 2013;162(3 Suppl):S107–14.
9. WHO. Born too soon: the global action report on preterm birth. Geneva (Switzerland): WHO; 2012.
10. UNICEF/WHO. UNICEF–WHO low birthweight estimates: levels and trends 2000–2015. Geneva (Switzerland): WHO; 2019.
11. Sania A, Smith ER, Manji K, Duggan C, Masanja H, Kisenge R, Msamanga G, Urassa W, Fawzi W. Neonatal and infant mortality risk associated with preterm and small for gestational age births in Tanzania: individual level pooled analysis using the intergrowth standard. J Pediatr 2018;192:66–72.e4.
12. Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, Mathers C, Rivera J. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet North Am Ed 2008;371(9608):243–60.
13. Katz J, Wu LA, Mullany LC, Coles CL, Lee ACC, Kozuki N, Tielsch JM. Prevalence of small-for-gestational-age and its mortality risk varies by choice of birth-weight-for-gestation reference population. PLoS One 2014;9(3):e92074.
14. Abu-Saad K, Fraser D. Maternal nutrition and birth outcomes. Epidemiol Rev 2010;32(1):5–25.
15. Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, de Onis M, Ezzati M, Grantham-Mcgregor S, Katz J, Martorell R, et al. Maternal and child undernutrition and overweight in low-income and middle-income countries. Lancet North Am Ed 2013;382(9890): 427–51.
16. Imdad A, Bhutta ZA. Nutritional management of the low birth weight/preterm infant in community settings: a perspective from the developing world. J Pediatr 2013;162(3 Suppl):S107–14.
17. King JC. Physiology of pregnancy and nutrient metabolism. Am J Clin Nutr 2000;71(5):1218S–25S.
18. Dewey KG. Reducing stunting by improving maternal, infant and young child nutrition in regions such as South Asia: evidence, challenges and opportunities. Matern Child Nutr 2016;12(Suppl 1):27–38.
19. Torheim L, Ferguson E, Penrose K, Arimond M. Women in resource-poor settings are at risk of inadequate intakes of multiple micronutrients. J Nutr 2010;140(11):2051S–8S.
20. Arimond M, Wiesmann D, Becquey E, Carriquiry A, Daniels MC, Deitchler M, Fanou-Fogny N, Joseph ML, Kennedy G, Martin-Prevel Y, et al. Simple food group diversity indicators predict micronutrient adequacy of women's diets in 5 diverse, resource-poor settings. J Nutr 2010;140(11):2059S.
21. Grieger JA, Clifton VL. A review of the impact of dietary intakes in human pregnancy on infant birthweight. Nutrients 2015;7(1): 153–78.
22. Hu FB. Dietary pattern analysis: a new direction in nutritional epidemiology. Curr Opin Lipidol 2002;13(1):3–9.
23. Saaka M. Maternal dietary diversity and infant outcome of pregnant women in northern Ghana. Int J Child Health Nutr 2012; 1(2):148–56.
24. Zerfu TA, Umeta M, Baye K. Dietary diversity during pregnancy is associated with reduced risk of maternal anemia, preterm delivery, and low birth weight in a prospective cohort study in rural Ethiopia. Am J Clin Nutr 2016;103(6):1482.
25. FAO. Minimum dietary diversity for women: A guide to measurement. Rome (Italy): FAO/USAID; 2016.
26. Martin-Prével Y, Allemand P, Wiesmann D, Arimond M, Ballard T, Deitchler M, Dop MC, Kennedy G, Lee WT, Mousi M. Moving forward on choosing a standard operational indicator of women's dietary diversity. Rome (Italy): FAO; 2015.
27. Rifas-Shiman SL, Willett WC, Lobb R, Kotch J, Dart C, Gillman MW. PrimeScreen, a brief dietary screening tool: reproducibility and comparability with both a longer food frequency questionnaire and biomarkers. Public Health Nutr 2001;4(2):249–54.
28. Fung TT, Isanaka S, Hu FB, Willett WC. International food group-based diet quality and risk of coronary heart disease in men and women. Am J Clin Nutr 2018;107(1):120–9.
29. Gicevic S, Gaskins AJ, Fung TT, Rosner B, Tobias DK, Isanaka S, Willett WC. Evaluating pre-pregnancy dietary diversity vs. dietary quality scores as predictors of gestational diabetes and hypertensive disorders of pregnancy. PLoS One 2018;13(4): e0195103–e.
30. Fung TT, Isanaka S, Hu FB, Willett WC. International food group-based diet quality and risk of coronary heart disease in men and women. Am J Clin Nutr 2018;107(1):120–9.
31. Fawzi WW, Msamanga GI, Urassa W, Hertzmark E, Petraro P, Willett WC, Spiegelman D. Vitamins and perinatal outcomes among HIV-negative women in Tanzania. N Engl J Med 2007;356(14): 1423–31.
32. Lukmanji ZHE, Mlingi N, Assey V, Ndossi G, Fawzi W. Tanzania food composition tables. Dar es Salaam (Tanzania): Muhimbili University of Health and Allied Sciences, Tanzania Food and Nutrition Centre/Harvard School of Public Health; 2008.
33. Holmes MD, Dalal S, Sewram V, Diamond MB, Adebamowo SN, Ajayi IO, Adebamowo C, Chiwanga FS, Njelekela M, Laurence C, et al. Consumption of processed food dietary patterns in four African populations. Public Health Nutr 2018;21(8):1529–37.
34. Villar J, Cheikh Ismail L, Victora CG, Ohuma EO, Bertino E, Altman DG, Lambert A, Papageorghiou AT, Carvalho M, Jaffer YA, et al. International standards for newborn weight, length, and head circumference by gestational age and sex: the Newborn Cross-Sectional Study of the INTERGROWTH-21st Project. Lancet North Am Ed 2014;384(9946):857–68.
35. Greenland S. Model-based estimation of relative risks and other epidemiologic measures in studies of common outcomes and in case–control studies. Am J Epidemiol 2004;160(4):301–5.
36. Filmer D, Pritchett LH. Estimating wealth effects without expenditure data-or tears: an application to educational enrollments in states of India. Demography 2001;38(1):115–32.
37. Rodriguez-Bernal CL, Rebagliato C, Chatzi L, Carbonell CC, Martos C, Ballester F. Maternal diet quality and pregnancy outcomes. Diet Quality 2013; 65–79.
38. Groenwold RHH, White IR, Donders ART, Carpenter JR, Altman DG, Moons KGM. Missing covariate data in clinical research: when and when not to use the missing-indicator method for analysis. Can Med Assoc J 2012;184(11):1265–9.
39. Willett WC, Stampfer MJ. Current evidence on healthy eating. Annu Rev Public Health 2013;34:77–95.
40. Sen S, Rifas-Shiman SL, Shivappa N, Wirth MD, Hébert JR, Gold DR, Gillman MW, Oken E. Dietary inflammatory potential during pregnancy is associated with lower fetal growth and breastfeeding failure: results from Project Viva. J Nutr 2016;146(4): 728–36.
41. Keding G. Nutrition transition in rural Tanzania and Kenya. World Rev Nutr Diet 2016;115:68.
42. Keding GB, Msuya JM, Maass BL, Krawinkel MB. Dietary patterns and nutritional health of women: the nutrition transition in rural Tanzania. Food Nutr Bull 2011;32(3):218–26.
43. Popkin BM. Global nutrition dynamics: the world is shifting rapidly toward a diet linked with noncommunicable diseases. Am J Clin Nutr 2006;84(2):289–98.
44. Kind KL, Moore VM, Davies MJ. Diet around conception and during pregnancy—effects on fetal and neonatal outcomes. Reprod Biomed Online 2006;12(5):532–41.
45. Bhutta Zulfiqar A, Imdad A. Effect of balanced protein energy supplementation during pregnancy on birth outcomes. BMC Public Health 2011;11:S17.
46. Changamire FT, Mwiru RS, Peterson KE, Msamanga GI, Spiegelman D, Petraro P, Urassa W, Fawzi WW. Effect of multivitamin supplements on weight gain during pregnancy among HIV-negative women in Tanzania. Maternal Child Nutr 2015;11(3): 297–304.
47. Gruszfeld D, Socha P. Early nutrition and health: short- and long-term outcomes. World Rev Nutr Diet 2013;108:32–9.
48. Romero R, Chaiworapongsa T, Espinoza J. Micronutrients and intrauterine infection, preterm birth and the fetal inflammatory response syndrome. J Nutr 2003;133(5):1668S–73S.
49. West KP, Shamim AA, Mehra S, Labrique AB, Ali H, Shaikh S, Klemm RDW, Wu LSF, Mitra M, Haque R, et al. Effect of maternal multiple micronutrient vs. iron–folic acid supplementation on infant mortality and adverse birth outcomes in rural Bangladesh: the JiVitA-3 randomized trial. JAMA 2014;312(24):2649–58.
50. Palmer AC. Nutritionally mediated programming of the developing immune system. Adv Nutr 2011;2(5):377–95.
51. Poston L, Igosheva N, Mistry HD, Seed PT, Shennan AH, Rana S, Karumanchi SA, Chappell LC. Role of oxidative stress and antioxidant

supplementation in pregnancy disorders. Am J Clin Nutr 2011;94(Suppl 6):1980S–5S.
52. Thorne-Lyman A, Spiegelman D, Fawzi WW. Is the strength of association between indicators of dietary quality and the nutritional status of children being underestimated? Maternal Child Nutr 2014;10(1):159–60.
53. Gicevic S, Gaskins AJ, Fung TT, Rosner B, Sabanovic E, Milesevic J, Kadvan A, Kremic E, Willett W. Demographic and socio-economic predictors of diet quality among adults in Bosnia and Herzegovina. Public Health Nutr 2019;22(17):3107–17.
54. Willett W. Nutritional epidemiology. New York: Oxford University Press; 2012.
55. Harland KK, Saftlas AF, Wallis AB, Yankowitz J, Triche EW, Zimmerman MB. Correction of systematic bias in ultrasound dating in studies of small-for-gestational-age birth: an example from the Iowa Health in Pregnancy Study. Am J Epidemiol 2012;176(5):443–55.