



Applied nutritional investigation

Maternal dietary patterns are associated with human milk composition in Chinese lactating women



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ABSTRACT

Objectives: Dietary patterns are a useful tool to study the impact of overall maternal diet on human milk (HM) composition beyond single foods or nutrients. The present study aimed to identify dietary patterns among Chinese lactating women and assess their associations with HM macronutrient composition.

Methods: Dietary intake data and HM samples were collected from 122 Chinese mothers at three to five study visits during the first 52 d postpartum. Dietary patterns were derived using principal component analysis. Cross-sectional associations of dietary patterns and HM macronutrients were assessed using multivariable linear regression models adjusted for total energy intake. All analyses were done separately for colostrum (postpartum days 0–7) and mature milk (postpartum days 8–52).

Results: Four dietary patterns were identified: high-in-animal-foods, high-in-eggs, high-in-plant-foods, and high-in-fruits. Compared with the lowest tertile (T1), participants in the highest tertile (T3) of the high-in-animal-foods and high-in-plant-foods patterns had lower protein (respectively, T3 – T1 = –1.09 g/100 mL, $P_{\text{trend}} = 0.002$; T3 – T1 = –0.54 g/100 mL, $P_{\text{trend}} = 0.001$) and higher fat (respectively, T3 – T1 = 0.86 g/100 mL, $P_{\text{trend}} = 0.040$; T3 – T1 = 0.40 g/100 mL, $P_{\text{trend}} = 0.004$) concentrations in colostrum. In contrast, in mature milk the high-in-animal-foods pattern was positively associated with carbohydrates (T3 – T1 = 0.53 g/100 mL, $P_{\text{trend}} = 0.008$) and the high-in-plant-foods pattern was negatively associated with fat (T3 – T1 = –0.64 g/100 mL, $P_{\text{trend}} = 0.002$). The high-in-eggs pattern was weakly positively associated with protein concentration in mature milk (T3 – T1 = 0.10 g/100 mL, $P_{\text{trend}} = 0.023$).

Conclusions: Maternal dietary patterns with high proportions of animal and plant-based foods were associated with higher fat and lower protein concentrations in colostrum. Different associations were found in mature milk. Dietary-pattern analysis provides an opportunity to characterize total diet and may be more predictive of HM composition than single foods or nutrients.

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Introduction

Human milk (HM) is the best source of nutrition for both term and preterm infants. The World Health Organization (WHO) recommends that mothers exclusively breastfeed their babies for 6 mo and continue breastfeeding for 2 y or longer [1]. HM has been demonstrated to provide a myriad of benefits, from reducing morbidity and mortality due to infectious diseases to improving the infant's neurocognitive development and protecting against the risk of obesity and other non-communicable diseases in later life

[2,3]. These beneficial effects of HM have been linked to the presence of bioactive components and live cells, many of which cannot be added to infant formula or cannot be maintained throughout the shelf life of the product [2,3].

It is well known that HM changes in composition over the course of lactation [4,5]. Moreover, a growing body of research indicates that the macronutrient content of HM is affected by the mother's diet and nutrient stores [6–8]. Concentrations of total fat and fatty acids in HM are significantly affected by dietary intake [9], whereas protein and lactose are comparatively resistant to variation in intake [8,10,11]. Yet although several studies have reported associations between dietary intakes of single nutrients or foods and HM composition, a systematic review by Bravi et al. [12] concluded that strong scientific evidence on the direct relationship between maternal dietary intake and HM composition is still lacking.

Most studies have investigated associations between the dietary intake of single nutrients and their presence in HM. It is often difficult to separate specific effects of nutrients, because of the highly interrelated nature of dietary exposure. For example, deficiencies or excesses of one nutrient influence the requirements for others. Also, nutrients are not consumed in isolation, and important synergies among and within foods likely exist; the joint effect of dietary components may be greater than the individual effects of single foods and nutrients [13].

In the present study, we aimed to identify dietary patterns among Chinese lactating women and to investigate the association between maternal diet during lactation and HM macronutrient composition, using multivariable statistical techniques that consider intercorrelations and interactions between multiple components of the diet. Information on maternal diet and HM composition data were collected during the first 52 d postpartum of a sample of 122 Chinese mothers who give birth to healthy term-born infant [14]. This is one of the few studies investigating dietary patterns during lactation and their association with HM macronutrient composition.

Materials and methods

The human milk samples included were collected from 122 mothers participating in the MuRu study. The MuRu study (Human Milk Profiles and Dietary Intake of Chinese Lactating Mothers during Early Lactation Period in Shanghai) was an exploratory, observational, single-center trial that aimed to study the association between dietary intake and HM composition of Chinese mothers who gave birth to healthy term-born infants.

Participants

Details on participant recruitment can be found elsewhere [14]. In short, the study was conducted by researchers of Shanghai Children's Medical Center. Healthy Chinese mothers ages 20 to 40 y were recruited from the obstetrics departments of Renji Hospital (a tertiary general hospital) and from the Shanghai First Maternity and Infant Hospital. Women recruited from Renji Hospital were taken care of by their families after discharge from the hospital (Community group), whereas women recruited from the Shanghai First Maternity and Infant Health Hospital stayed at the clinic for 4 wk postpartum (Maternal Care Center [MCC] group). Ethical approval was obtained from the institutional review board of Shanghai Children's Medical Center (SCMCIRBK2013026). The sample size of the original study [14] was based on recommendations of the Expert Group on Food Consumption Data to include at least 130 participants of each population group (in this study, lactating women) in dietary surveys [15] and an expected dropout rate of 20% at 52 d postpartum. A total of 179 potentially eligible participants were screened, 33 of whom (18%) were excluded because of a deviation from inclusion or exclusion criteria [14]. During the observational period, 24 (13%) mothers discontinued the study before the last visit—lost to follow-up ($n = 20$), experienced an adverse event (i.e., mastitis; $n = 1$), and withdrew early ($n = 3$)—ultimately yielding a final sample size of 122 women (92 in the Community group and 30 in the MCC group). All participants provided informed consent.

Data collection

Five visits were defined to collect data for the MCC group, at 0 to 7 d (V1), 8 to 13 d (V2), 14 to 21 d (V3), 22 to 35 d (V4), and 36 to 51 d (V5) after delivery. The Community group attended only V1, V4, and V5. Demographic and socioeconomic characteristics and medical history were recorded at study entry [14].

Dietary assessment

At each visit, dietary intake information was collected via 1-d (for the Community group) or 3-d (for the MCC group) food records. The information included the name of the food or drink, including brand, food type (raw or cooked), cooking method (boiled, fried, or baked) and food texture (e.g., dry, watery, or thick). Additionally, recipe and portion-size details, as well as photographs before and after every meal, were collected. Subsequently, based on the collected information, estimation of the quantity of food consumed by each participant was made by referring to the Food Graph Reference for Retrospective Dietary Survey designed by Professor Wang of Nanjing Medical University [14]. Foods were assigned to one of 10 food groups (beans, eggs, fish/shrimp, fruits, vegetables, grains, meat/poultry, milk/dairy products, oil, tubers). The China Food Composition Book [14,16] was used to convert food intake into nutrient intakes (macronutrients, fatty acids, micronutrients).

HM collection and analysis

At each visit, an HM sample was collected. Mothers expressed a minimum of 10 mL of HM (foremilk), ideally between 06:00 h and 10:00 h, by breast pump or by hand, into sterile hard plastic containers. Immediately after expression, the containers were put on ice at home (Community group) or at the Maternal Care Center (MCC group). Collected samples at home were transported to the hospital in ice boxes. Macronutrients were analyzed immediately upon arrival of the samples at the hospital. The remainder of the samples was divided into 1-mL aliquots and stored at -80°C . From the HM sample, macronutrient content (protein, lipids, carbohydrate, total energy, and total solids) was analyzed at the hospital using a mid-infrared Miris Human Milk Analyzer (MIRIS AB, Uppsala, Sweden). For this purpose, a 6-mL aliquot was mixed with a suitable homogenizer and subjected to mid-infrared analysis using the Miris device according to the manufacturer's user manual. Each sample was analyzed in duplicate.

Statistical analyses

The stability of dietary intake and HM composition over time were assessed using analysis of variance with adjustment by Tukey's honestly significant difference test.

Principal component analysis with orthogonal rotation was used to derive uncorrelated dietary patterns from the 10 food groups. This is an established approach to study dietary patterns [17,18]. To select the number of patterns, different criteria were combined (break in the scree plot, factors with eigenvalues >1.0 , and interpretability). For each pattern, food items with factor loadings of $\geq|0.3|$ were considered to contribute significantly to the dietary pattern. Dietary patterns were named according to the food items with the greatest distinguishable factor loading.

Unadjusted means of demographic and dietary characteristics (total energy in kcal/d; total carbohydrates, protein, and fat expressed as the percentage of total energy derived from each macronutrient [E%]; calcium, magnesium, phosphorus, potassium, sodium, iron, zinc, vitamins B1, B2, and C, and cholesterol in mg/d; selenium in $\mu\text{g/d}$; vitamin A in $\mu\text{g RAE/d}$; niacin in mg NE/d; and vitamin E in mg $\alpha\text{TE/d}$ and dietary fiber in g/d) were calculated by tertiles of the dietary patterns. Multivariable linear regression models assessed the cross-sectional associations of dietary patterns and HM macronutrients. Separate regression models were conducted for each HM macronutrient as dependent variables and the four dietary patterns as independent variables. Dietary patterns were modeled as tertiles of consumption and continuously, using the P value for the continuous model to assess the linear trend. A minimal model (model 1) included only the dietary pattern; it was then further adjusted for total energy (continuous; model 2).

All analyses were done in SAS version 4.7.3 on Life Science Analytics Framework (SAS, Cary, NC).

Results

The study population had a mean age of 29.3 ± 3.4 y (range, 20.4–39.4), with a mean baseline body mass index of 24.0 ± 3.1 kg/m^2 . There were no apparent differences between the two study groups, except that the MCC group had a higher percentage of participants in the higher income bracket and a higher number of homemakers in the MCC group [14].

Dietary intake data were available for all participants ($n = 122$). HM was obtained from 84 participants at V1 and from all 122 participants at least at one of the subsequent visits (V2–V5). Not all

participants provided an HM sample at each visit; the reasons for this were mainly no or a limited amount of human milk and inadequate storing of samples.

Dietary intake was found to be reasonably stable over the 52-d study period (Supplementary Tables 1 and 2). Therefore, we decided to use the average dietary intake over the study period to identify dietary patterns. In contrast to dietary intake, HM composition significantly changed over time. In particular, statistically significant differences in macronutrient concentrations were observed between V1 and the subsequent visits. Therefore, analyses were performed separately for colostrum (V1; postpartum days 0–7) and mature milk (V2–V5; postpartum days 8–52).

Dietary patterns

Principal component analysis revealed four dietary patterns that explained 57% of the total variance (Fig. 1, Supplementary Table E3):

- High in animal foods: High scores on this pattern reflect high consumption of oils, vegetables, meat/poultry, grains, beans, milk/dairy, and fish/shrimp.
- High in eggs: High scores on this pattern reflect high consumption of eggs and fruit and low consumption of fish/shrimp and vegetables.
- High in plant foods: High scores on this pattern reflect high consumption of tubers, vegetables, and milk/dairy, and low consumption of grain, eggs, and meat/poultry.
- High in fruits: High scores on this pattern reflect high consumption of fruit and fish/shrimp and low consumption of beans and milk/dairy.

Demographic characteristics across dietary patterns

Baseline age and body mass index were similar across and within dietary patterns (Table 1). Participants who scored high on the high-in-animal-foods and high-in-plant patterns were more

likely to be in the MCC group, whereas those who scored high on the high-in-eggs pattern were more likely to be in the Community group. Mothers in the highest tertiles of the high-in-animal-foods and high-in-plant-foods patterns were more likely to have a higher income. Almost all participants had completed tertiary education.

Dietary characteristics across dietary patterns

Across tertiles of the high-in-animal-foods pattern, the intake of total energy and relative intakes (in %) of protein and fat increased, whereas the relative intake of carbohydrates decreased (Table 2). Consistent with high loadings of meat/poultry and milk/dairy in the high-in-animal-foods pattern, dietary intakes of iron, zinc, selenium, and calcium increased over the tertiles. However, even in the highest tertile, average calcium intake did not reach the Estimated Average Requirement (EAR; Table 3). Consistent with high loadings of vegetables in this dietary pattern, intakes of vitamin C and dietary fiber increased over the tertiles. The EAR for vitamin C was reached only in the highest tertile, whereas intake of dietary fiber was far below the EAR (<50%) in all tertiles.

Across tertiles of the high-in-eggs pattern, the intake of total energy and the relative intake of carbohydrates increased, whereas the relative intake of protein decreased and that of fat was stable. Consistent with the high loading of eggs in this dietary pattern, intake of cholesterol and vitamins A, B1, and B2 increased over the tertiles.

Across tertiles of the high-in-plant-foods pattern, the intake of total energy decreased and the relative intakes of protein, carbohydrates, and fat were stable. As for the high-in-animal-foods pattern, high loadings of vegetables in the high-in-plant-foods pattern were associated with increased intakes of vitamin C and dietary fiber over the tertiles. Yet in this dietary pattern average intakes of vitamin C and dietary fiber were below the EAR, even in the highest tertile.

Across tertiles of the high-in-fruits pattern, the intake of total energy and relative intake of carbohydrates increased, whereas the relative intake of fat decreased and that of protein was stable. Consistent with the high loading of fruits in this dietary pattern, intake of dietary fiber and vitamin C increased over the tertiles.

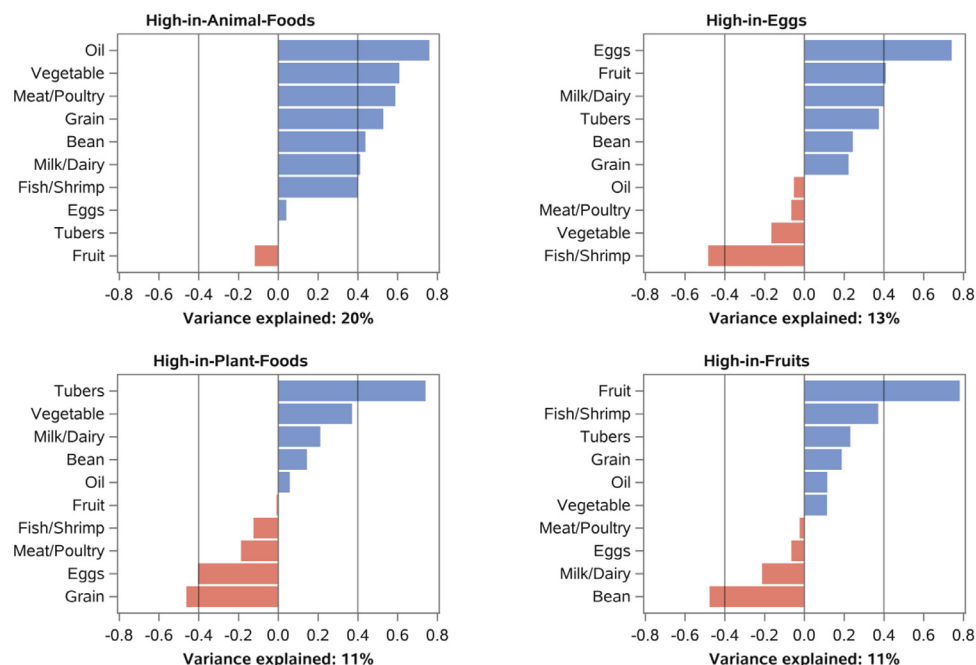


Fig. 1. Factor loadings for each food group in the dietary patterns derived from principal component analysis. Bars represent food-group loadings on the dietary pattern; blue food groups have a positive loading (>0.0) on the specific pattern, red food groups have a negative loading (<0.0) on the pattern.

Table 1
Demographic characteristics in each dietary pattern according to tertile

Characteristic	High-in-animal-foods			High-in-eggs			High-in-plant-foods			High-in-fruits		
	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3
Age, y	28.9 (3.27)	29.6 (3.00)	29.5 (3.86)	28.8 (3.83)	30.0 (3.47)	29.3 (2.76)	28.6 (2.70)	29.7 (3.63)	29.8 (3.67)	29.0 (3.51)	29.2 (3.52)	29.8 (3.14)
BMI, kg/m ²	23.8 (3.09)	24.2 (2.91)	24.0 (3.36)	24.4 (3.43)	23.7 (2.71)	23.9 (3.17)	24.3 (2.91)	23.8 (2.90)	24.0 (3.50)	24.1 (2.92)	23.9 (3.07)	24.1 (3.36)
Study group	40 (100.0%)	34 (82.9%)	18 (43.9%)	30 (75.0%)	23 (56.1%)	39 (95.1%)	38 (95.0%)	24 (58.5%)	30 (73.2%)	28 (70.0%)	30 (73.2%)	34 (82.9%)
MCC	0 (0.0%)	7 (17.1%)	23 (56.1%)	10 (25.0%)	18 (43.9%)	2 (4.9%)	2 (5.0%)	17 (41.5%)	11 (26.8%)	12 (30.0%)	11 (26.8%)	7 (17.1%)
Highest level of education completed	3 (7.5%)	0 (0.0%)	2 (4.9%)	2 (5.0%)	1 (2.4%)	2 (4.9%)	3 (7.5%)	0 (0.0%)	2 (4.9%)	3 (7.5%)	2 (4.9%)	0 (0.0%)
Tertiary	37 (92.5%)	41 (100.0%)	39 (95.1%)	38 (95.0%)	40 (97.6%)	39 (95.1%)	37 (92.5%)	41 (100.0%)	39 (95.1%)	37 (92.5%)	39 (95.1%)	41 (100.0%)
Current occupational status	31 (77.5%)	37 (90.2%)	34 (82.9%)	35 (87.5%)	35 (85.4%)	32 (78.0%)	35 (87.5%)	35 (85.4%)	32 (78.0%)	35 (87.5%)	32 (78.0%)	35 (85.4%)
Working	2 (5.0%)	0 (0.0%)	2 (4.9%)	1 (2.5%)	1 (2.4%)	2 (4.9%)	2 (5.0%)	0 (0.0%)	2 (4.9%)	2 (5.0%)	1 (2.4%)	1 (2.4%)
Self-employed	2 (5.0%)	1 (2.4%)	0 (0.0%)	1 (2.5%)	1 (2.4%)	1 (2.4%)	1 (2.5%)	1 (2.4%)	1 (2.4%)	0 (0.0%)	1 (2.4%)	1 (2.4%)
Unemployed	1 (2.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (2.4%)	1 (2.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (2.4%)	0 (0.0%)
Studying	4 (10.0%)	3 (7.3%)	5 (12.2%)	3 (7.5%)	4 (9.8%)	5 (12.2%)	1 (2.5%)	5 (12.2%)	6 (14.6%)	3 (7.5%)	5 (12.2%)	4 (9.8%)
Homemaker	10 (25.0%)	1 (2.4%)	4 (9.8%)	8 (20.0%)	2 (4.9%)	5 (12.2%)	8 (20.0%)	4 (9.8%)	3 (7.3%)	7 (17.5%)	5 (12.2%)	3 (7.3%)
Annual household income, RMB	21 (52.5%)	31 (75.6%)	24 (58.5%)	24 (60.0%)	22 (53.7%)	30 (73.2%)	26 (65.0%)	25 (61.0%)	25 (61.0%)	20 (50.0%)	24 (58.5%)	32 (78.0%)
<100,000	8 (20.0%)	7 (17.1%)	7 (17.1%)	5 (12.5%)	13 (31.7%)	4 (9.8%)	5 (12.5%)	5 (12.5%)	7 (17.1%)	9 (22.5%)	9 (22.5%)	4 (9.8%)
300,000–500,000	1 (2.5%)	2 (4.9%)	6 (14.6%)	3 (7.5%)	4 (9.8%)	2 (4.9%)	1 (2.5%)	2 (4.9%)	6 (14.6%)	4 (10.0%)	3 (7.3%)	2 (4.9%)

BMI, body mass index; MCC, Maternal Care Center

All values are mean (SD) or n (%)

Association between derived dietary patterns and HM composition

Table 4 gives mean concentrations of HM macronutrients, separately for the first week postpartum (colostrum) and after the first week postpartum (mature milk), per tertile of the dietary patterns derived by principal component analysis.

After adjustment for total energy, in colostrum protein concentration was inversely associated with the high-in-animal-foods ($P_{\text{trend}} = 0.002$) and high-in-plant-foods ($P_{\text{trend}} = 0.001$) patterns, whereas fat concentration was positively associated with these patterns ($P_{\text{trend}} = 0.040$ and 0.004 , respectively). Comparing the highest tertile (T3) with the lowest (T1), mean protein was 1.09 g/100 mL lower for the high-in-animal-foods pattern and 0.54 g/100 mL lower for the high-in-plant-foods, whereas mean fat concentration was 0.86 g/100 mL higher in the high-in-animal-foods pattern and 0.40 g/100 mL higher in the high-in-plant-foods pattern. Additionally, participants who scored high on these dietary patterns were more likely to have higher carbohydrate concentrations in colostrum, although after adjustment for total energy, this change in the high-in-animal-foods dietary pattern did not reach statistical significance (high-in-animal-foods: T3 – T1 = 0.66 g/100 mL, $P_{\text{trend}} = 0.14$; high-in-plant-foods: T3 – T1 = 0.50 g/100 mL, $P_{\text{trend}} = 0.016$).

In mature milk, the high-in-animal-foods pattern was positively associated with carbohydrate concentration ($P_{\text{trend}} = 0.008$), with a mean 0.53 g/100 mL higher in T3 than in T1. The high-in-plant-foods pattern was inversely associated with fat concentration ($P_{\text{trend}} = 0.002$), with a mean 0.64 g/100 mL lower in T3 than in T1.

In the high-in-egg pattern, T3 had slightly higher protein concentrations in mature milk than T1 (T3 – T1 = 0.10 g/100 mL, $P_{\text{trend}} = 0.023$). The high-in-fruits pattern was not associated with macronutrients in colostrum or in mature milk.

Discussion

Current knowledge on the relationship between maternal diet and the composition of HM is largely based on studies investigating associations between the dietary intake of single nutrients and their presence in HM. However, it is often difficult to separate the specific effects of nutrients or foods, because of the highly interrelated nature of dietary exposure. The dietary-pattern approach considers correlations and interactions between nutrients and foods and therefore better reflects the complexity of diet. This is one of the few studies to investigate the association between maternal dietary patterns during the puerperium period and HM macronutrient composition.

Four dietary patterns were derived using principal component analysis among 122 lactating mothers in China: high-in-animal-foods, high-in-eggs, high-in-plant-foods, and high-in-fruits. The high-in-animal-foods pattern was high in animal products (i.e., meat/poultry, milk/dairy, and fish/shrimp) as well as oils, vegetables, and grains; the high-in-eggs pattern was high in eggs and fruits; the high-in-plant-foods pattern was high in plant-based products (i.e., tubers, vegetables, beans) and milk/dairy; and the high-in-fruits pattern reflected high intakes of fruits and fish/shrimp. Our description of the dietary patterns shows some similarities with other studies on dietary habits and patterns in the Chinese population. Recently, three studies evaluating dietary patterns among lactating women in China have been conducted. Tian et al. [19] identified four dietary patterns among 274 lactating women ranging from 22 d to 6 mo postpartum in Changchun city, Jilin province, in northeast China. Participants with dietary pattern 1 ate mainly mushrooms and algae, meat, and marine products (as in our high-in-animal-foods dietary pattern); those with pattern 2 ate mainly soybean products, nuts, and dairy products (as in our high-in-plant-foods dietary pattern); those with pattern 3 ate mainly fruits and vegetables (as in our high-in-fruits dietary pattern); and those with pattern

Table 2
Energy and macro- and micronutrient intakes across tertiles of dietary patterns

Intake	High-in-animal-Foods			High-in-eggs			High-in-plant-foods			High-in-fruits		
	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3
Energy and macronutrients												
Total energy, kcal/d	1718.2 (289.28)	2109.6 (290.05)	2443.3 (314.96)	2036.9 (443.71)	2023.6 (315.89)	2218.4 (464.23)	2285.6 (431.39)	1971.7 (372.37)	2027.7 (393.50)	1971.6 (413.08)	2090.4 (389.04)	2215.4 (428.55)
Total carbohydrate, E%	47.6 (7.11)	45.7 (5.55)	43.7 (3.76)	43.5 (5.21)	46.3 (5.22)	47.1 (6.41)	45.4 (5.18)	45.5 (6.05)	46.1 (6.24)	43.5 (5.02)	45.5 (5.42)	47.9 (6.20)
Total protein, E%	18.5 (3.06)	19.2 (2.39)	20.8 (2.19)	20.5 (2.78)	19.8 (2.83)	18.3 (2.10)	19.3 (2.51)	20.1 (3.25)	19.1 (2.31)	19.7 (2.84)	19.8 (2.41)	19.0 (2.90)
Total fat, E%	33.3 (5.59)	34.6 (5.43)	35.1 (3.84)	35.5 (5.31)	33.5 (4.09)	34.0 (5.47)	34.6 (5.13)	34.0 (5.00)	34.4 (5.05)	36.2 (4.66)	34.1 (4.51)	32.7 (5.37)
Micronutrients												
Calcium, mg/d	436.4 (215.6)	598.2 (198.4)	789.0 (176.5)	614.9 (242.3)	638.8 (233.6)	574.3 (254.8)	573.1 (238.9)	631.9 (274.0)	622.0 (214.9)	627.0 (246.4)	649.2 (244.6)	552.0 (233.6)
Magnesium, mg/d	274.8 (59.7)	342.9 (75.8)	416.9 (64.3)	347.0 (96.2)	347.3 (84.6)	342.0 (86.0)	349.0 (89.7)	338.3 (91.6)	349.1 (85.3)	330.6 (85.0)	347.7 (88.9)	357.7 (90.9)
Phosphorus, mg/d	1060.1 (207.1)	1329.3 (222.3)	1617.8 (221.8)	1323.9 (324.4)	1327.4 (315.0)	1362.4 (308.6)	1412.2 (312.5)	1291.8 (333.2)	1311.7 (288.8)	1260.6 (294.5)	1381.9 (294.7)	1369.6 (342.9)
Potassium, mg/d	1809.4 (428.4)	2328.2 (478.1)	2704.1 (402.1)	2233.1 (611.3)	2259.8 (521.1)	2359.1 (576.6)	2286.9 (572.6)	2172.9 (561.1)	2393.5 (563.8)	2016.2 (553.2)	2311.8 (462.8)	2518.7 (579.4)
Sodium, mg/d	2557.8 (798.7)	2836.4 (767.9)	3659.4 (615.4)	3167.4 (986.0)	3054.5 (742.3)	2846.6 (839.6)	3151.1 (964.1)	2942.2 (908.6)	2974.7 (707.3)	2926.7 (993.2)	3031.4 (778.5)	3104.5 (820.7)
Iron, mg/d	18.1 (4.34)	23.6 (6.27)	31.5 (8.25)	25.1 (9.21)	23.9 (6.96)	24.4 (9.24)	24.9 (8.56)	24.6 (9.10)	24.0 (7.91)	24.0 (7.83)	25.1 (9.44)	24.2 (8.22)
Selenium, µg/d	63.0 (24.7)	78.7 (26.3)	118.9 (36.4)	95.6 (39.2)	88.7 (42.4)	77.2 (28.8)	88.6 (32.1)	87.5 (34.8)	85.3 (45.7)	79.2 (34.8)	94.3 (39.0)	87.6 (38.6)
Zinc, mg/d	10.8 (2.27)	14.2 (2.82)	18.0 (2.68)	14.9 (4.15)	14.5 (3.85)	13.8 (3.76)	14.9 (3.88)	14.4 (4.19)	13.8 (3.68)	13.8 (3.69)	14.7 (3.90)	14.6 (4.18)
Vitamin A, µg RAE/d	869.6 (579.8)	1294.7 (1275.8)	1439.8 (829.1)	1113.5 (992.2)	1161.6 (592.0)	1334.9 (1217.4)	1221.7 (1205.8)	1242.0 (806.7)	1149.1 (864.1)	1243.0 (785.6)	1108.8 (850.8)	1261.5 (1216.7)
Vitamin B1, mg/d	0.99 (0.21)	1.19 (0.23)	1.30 (0.18)	1.09 (0.24)	1.13 (0.22)	1.27 (0.25)	1.25 (0.23)	1.08 (0.20)	1.15 (0.28)	1.09 (0.20)	1.17 (0.26)	1.22 (0.26)
Vitamin B2, mg/d	1.17 (0.32)	1.62 (0.61)	2.01 (0.58)	1.51 (0.61)	1.59 (0.59)	1.71 (0.65)	1.65 (0.64)	1.54 (0.54)	1.62 (0.68)	1.57 (0.54)	1.65 (0.66)	1.60 (0.65)
Niacin, mg NE/d	17.8 (5.58)	22.4 (6.40)	28.4 (5.42)	23.5 (8.28)	22.0 (6.45)	23.1 (6.97)	24.6 (7.58)	21.6 (6.68)	22.6 (7.26)	21.4 (6.97)	22.4 (6.19)	24.9 (8.11)
Vitamin C, mg/d	73.3 (36.8)	108.4 (45.1)	136.9 (60.8)	101.9 (52.5)	115.6 (58.8)	101.7 (53.1)	87.7 (37.4)	106.5 (58.6)	124.7 (60.1)	83.6 (35.9)	116.8 (66.1)	118.5 (51.8)
Vitamin E, mg αTE/d	26.0 (5.44)	33.5 (5.93)	39.5 (5.62)	32.9 (8.78)	33.9 (7.35)	32.4 (7.54)	32.3 (7.85)	32.1 (7.60)	34.8 (8.05)	31.9 (8.33)	34.2 (7.85)	33.1 (7.45)
Cholesterol, mg/d	756.5 (248.6)	863.2 (315.8)	980.7 (250.5)	797.0 (260.1)	796.4 (220.1)	1008.0 (321.6)	1061.6 (308.8)	803.3 (211.4)	742.9 (229.7)	857.4 (235.5)	883.8 (306.5)	861.5 (315.8)
Dietary fiber, g/d	8.40 (2.68)	10.8 (3.44)	11.6 (2.33)	9.74 (3.43)	10.0 (2.57)	11.0 (3.29)	10.1 (2.73)	9.70 (2.61)	11.0 (3.83)	8.90 (2.33)	10.0 (3.03)	11.9 (3.27)

E%, percentage of total energy
All values are mean (SD)

Table 3

Mean (SD) percentage of estimated average requirement or adequate intake across tertiles of dietary patterns

Nutrient	High-in-animal-foods			High-in-eggs			High-in-plant-foods			High-in-fruits		
	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3
Calcium	53.9 (26.6)	73.9 (24.5)	97.4 (21.8)	75.9 (29.9)	78.9 (28.8)	70.9 (31.5)	70.8 (29.5)	78.0 (33.8)	76.8 (26.5)	77.4 (30.4)	80.2 (30.2)	68.2 (28.8)
Magnesium	98.1 (21.3)	122.5 (27.1)	148.9 (23.0)	123.9 (34.4)	124.1 (30.2)	122.2 (30.7)	124.6 (32.0)	120.8 (32.7)	124.7 (30.5)	118.1 (30.4)	124.2 (31.8)	127.8 (32.5)
Phosphorus	176.7 (34.5)	221.5 (37.1)	269.6 (37.0)	220.6 (54.1)	221.2 (52.5)	227.1 (51.4)	235.4 (52.1)	215.3 (55.5)	218.6 (48.1)	210.1 (49.1)	230.3 (49.1)	228.3 (57.2)
Potassium	75.4 (17.9)	97.0 (19.9)	112.7 (16.8)	93.1 (25.5)	94.2 (21.7)	98.3 (24.0)	95.3 (23.9)	90.5 (23.4)	99.7 (23.5)	84.0 (23.1)	96.3 (19.3)	105.0 (24.1)
Sodium	170.5 (53.3)	189.1 (51.2)	244.0 (41.0)	211.2 (65.7)	203.6 (49.5)	189.8 (56.0)	210.1 (64.3)	196.2 (60.6)	198.3 (47.2)	195.1 (66.2)	202.1 (51.9)	207.0 (54.7)
Iron	100.6 (24.1)	131.3 (34.8)	174.9 (45.8)	139.4 (51.2)	132.7 (38.7)	135.7 (51.4)	138.3 (47.6)	136.4 (50.6)	133.1 (43.9)	133.4 (43.5)	139.7 (52.5)	134.5 (45.7)
Selenium	96.9 (38.0)	121.1 (40.4)	183.0 (56.0)	147.1 (60.3)	136.4 (65.3)	118.8 (44.3)	136.3 (49.3)	134.5 (53.6)	131.2 (70.2)	121.8 (53.6)	145.0 (60.0)	134.8 (59.3)
Zinc	109.4 (22.9)	143.1 (28.5)	182.0 (27.1)	150.3 (41.9)	146.0 (38.9)	139.2 (38.0)	150.4 (39.2)	145.6 (42.3)	139.5 (37.1)	139.6 (37.3)	148.5 (39.4)	147.2 (42.2)
Vitamin A	98.8 (65.9)	147.1 (145.0)	163.6 (94.2)	126.5 (112.8)	132.0 (67.3)	151.7 (138.3)	138.8 (137.0)	141.1 (91.7)	130.6 (98.2)	141.3 (89.3)	126.0 (96.7)	143.4 (138.3)
Vitamin B1	82.1 (17.8)	99.2 (19.3)	108.7 (14.9)	90.5 (19.9)	93.9 (18.3)	105.8 (20.5)	104.2 (19.2)	90.1 (16.9)	96.2 (23.0)	91.1 (16.9)	97.5 (21.6)	101.7 (21.7)
Vitamin B2	97.9 (26.5)	134.8 (50.5)	167.7 (48.2)	125.6 (50.4)	132.7 (49.5)	142.8 (54.3)	137.6 (53.1)	128.6 (45.2)	135.2 (56.5)	130.7 (45.3)	137.2 (55.1)	133.3 (54.4)
Niacin	148.0 (46.5)	186.8 (53.3)	236.5 (45.2)	196.1 (69.0)	183.7 (53.7)	192.7 (58.0)	204.8 (63.2)	179.6 (55.7)	188.2 (60.5)	178.2 (58.1)	186.4 (51.6)	207.5 (67.6)
Vitamin C	58.7 (29.4)	86.7 (36.1)	109.5 (48.6)	81.5 (42.0)	92.5 (47.1)	81.4 (42.4)	70.1 (29.9)	85.2 (46.9)	99.8 (48.0)	66.8 (28.7)	93.4 (52.9)	94.8 (41.5)
Vitamin E	153.2 (32.0)	197.2 (34.9)	232.2 (33.1)	193.6 (51.7)	199.6 (43.2)	190.4 (44.4)	189.9 (46.2)	188.8 (44.7)	204.8 (47.4)	187.6 (49.0)	201.2 (46.2)	194.6 (43.8)
Dietary fiber	33.6 (10.7)	43.1 (13.8)	46.2 (9.3)	39.0 (13.7)	40.1 (10.3)	44.0 (13.2)	40.4 (10.9)	38.6 (10.5)	44.1 (15.3)	35.6 (9.3)	39.8 (12.1)	47.5 (13.1)

All values are mean (SD)

Table 4

Mean (SE) concentrations (g/100 mL) of macronutrients in colostrum and mature milk across tertiles of dietary patterns

		High-in-animal-foods				High-in-eggs				High-in-plant-foods				High-in-fruits			
		Tertile 1	Tertile 2	Tertile 3	P_{trend}^*	Tertile 1	Tertile 2	Tertile 3	P_{trend}^*	Tertile 1	Tertile 2	Tertile 3	P_{trend}^*	Tertile 1	Tertile 2	Tertile 3	P_{trend}^*
Colostrum	<i>n</i>	27	26	31		28	31	25		28	32	24		30	28	26	
Carbohydrates	Model 1 [†]	5.56 (0.13)	6.05 (0.14)	6.22 (0.12)	0.004	5.93 (0.14)	6.02 (0.13)	5.92 (0.15)	0.504	5.63 (0.13)	6.19 (0.13)	6.03 (0.14)	0.107	5.70 (0.13)	6.06 (0.14)	6.14 (0.14)	0.049
	Model 2 [‡]	5.56 (0.16)	6.05 (0.14)	6.22 (0.15)	0.142	5.97 (0.14)	6.03 (0.13)	5.85 (0.15)	0.117	5.55 (0.13)	6.24 (0.12)	6.05 (0.14)	0.016	5.76 (0.13)	6.04 (0.13)	6.09 (0.14)	0.156
Protein	Model 1	2.63 (0.15)	2.01 (0.15)	1.87 (0.14)	0.005	2.17 (0.16)	1.97 (0.15)	2.37 (0.16)	0.158	2.54 (0.15)	1.88 (0.14)	2.08 (0.16)	0.005	2.29 (0.15)	2.06 (0.16)	2.10 (0.16)	0.532
	Model 2	2.81 (0.18)	2.00 (0.15)	1.72 (0.16)	0.002	2.14 (0.16)	1.96 (0.15)	2.42 (0.17)	0.053	2.60 (0.15)	1.84 (0.14)	2.06 (0.16)	0.0009	2.26 (0.16)	2.07 (0.16)	2.13 (0.17)	0.760
Fat	Model 1	2.61 (0.18)	2.81 (0.18)	2.93 (0.17)	0.542	2.55 (0.17)	3.07 (0.16)	2.70 (0.18)	0.589	2.34 (0.16)	3.22 (0.15)	2.74 (0.17)	0.003	2.78 (0.17)	2.76 (0.18)	2.83 (0.18)	0.781
	Model 2	2.32 (0.21)	2.81 (0.18)	3.18 (0.19)	0.040	2.53 (0.17)	3.07 (0.16)	2.73 (0.18)	0.732	2.34 (0.16)	3.22 (0.15)	2.74 (0.17)	0.004	2.75 (0.17)	2.77 (0.18)	2.85 (0.19)	0.638
Mature milk	<i>n</i>	40	41	41		40	41	41		40	41	41		40	41	41	
Carbohydrates	Model 1	6.05 (0.12)	6.14 (0.12)	6.38 (0.12)	0.053	6.16 (0.12)	6.38 (0.12)	6.04 (0.12)	0.591	6.00 (0.12)	6.24 (0.12)	6.34 (0.12)	0.107	6.38 (0.12)	6.17 (0.12)	6.04 (0.12)	0.263
	Model 2	5.95 (0.15)	6.15 (0.12)	6.48 (0.15)	0.008	6.16 (0.12)	6.40 (0.12)	6.02 (0.12)	0.514	5.96 (0.13)	6.27 (0.12)	6.35 (0.12)	0.066	6.40 (0.13)	6.17 (0.12)	6.02 (0.12)	0.203
Protein	Model 1	1.48 (0.03)	1.43 (0.03)	1.39 (0.03)	0.077	1.39 (0.03)	1.44 (0.03)	1.47 (0.03)	0.052	1.42 (0.03)	1.46 (0.03)	1.42 (0.03)	0.491	1.44 (0.03)	1.45 (0.03)	1.41 (0.03)	0.454
	Model 2	1.48 (0.04)	1.43 (0.03)	1.39 (0.04)	0.175	1.38 (0.03)	1.43 (0.03)	1.48 (0.03)	0.023	1.43 (0.04)	1.45 (0.03)	1.41 (0.03)	0.266	1.43 (0.03)	1.45 (0.03)	1.42 (0.03)	0.641
Fat	Model 1	4.49 (0.17)	4.07 (0.17)	4.00 (0.17)	0.075	4.37 (0.17)	3.97 (0.17)	4.22 (0.17)	0.911	4.32 (0.17)	4.46 (0.17)	3.78 (0.17)	0.011	4.31 (0.17)	4.02 (0.17)	4.23 (0.17)	0.487
	Model 2	4.51 (0.21)	4.07 (0.17)	3.98 (0.21)	0.220	4.35 (0.17)	3.94 (0.17)	4.26 (0.17)	0.685	4.39 (0.17)	4.41 (0.17)	3.75 (0.17)	0.002	4.27 (0.18)	4.02 (0.17)	4.26 (0.17)	0.702

*Based on adjusted linear regression analysis with dietary pattern as continuous values

[†]Linear regression analysis with the dietary pattern in tertiles as the independent variable and the macronutrient in human milk as the dependent variable[‡]Model 1 plus energy (kcal/d)

4 ate mainly grains, potatoes, beans, and eggs (as in our high-in-eggs dietary pattern). Huang et al. [20] identified two dietary patterns among 305 lactating women in south central China. Those with pattern 1 ate mainly red meat, coarse cereals, fresh (leafy) vegetables, starchy roots and tubers, and animal milk, and consumed less soy milk and rice, whereas those with pattern 2 ate mainly fresh (non-leafy) vegetables, soy milk, fungi and algae, and fresh legumes, and consumed less poultry, candy and fast food, and nuts and seeds. In a subsequent study conducted by the same authors in a similar setting, three slightly different dietary patterns were defined [21]: lactating women with pattern 1 ate mainly fresh vegetables and legumes, those with pattern 2 ate mainly red meat, cereals, and eggs, and those with pattern 3 ate mainly fungi and algae, legumes, and soy milk. Interestingly, that study also explored associations between dietary patterns and HM macronutrients, finding that dietary pattern 2 was positively associated with the concentration of protein in human milk. The vast majority of HM samples (>85%) in that study were collected in the mature-milk period—that is, beyond postpartum day 8. Our results showing a higher protein concentration in mature milk of women consuming high amounts of eggs and cereals agrees with that study.

In a study among 7462 Chinese pregnant women, Balanced (high in meat, fish, vegetables, and dairy, as in our high-in-animal-foods pattern), Vegetarian (high in tubers, vegetables, and beans, as in our high-in-plant-foods pattern), and Snack (high in beverages, sweets, snacks, and fast foods) dietary patterns were identified [22]. Moreover, Zhang et al. identified Modern (high in meat, milk, vegetables, beans, and oils, as in our high-in-animal-foods pattern), Traditional (high in grains, vegetables, and fish, as in our high-in-fruits pattern), and Tuber (high in tubers, vegetables, and beans, and low in meat, fish, and eggs, as in our high-in-plant-foods pattern) dietary patterns in healthy adults (ages 18–80 y) in southwest China [23]. Yet none of these previously described dietary patterns fully corresponds to the four patterns we found. A likely explanation for this is our specific target group, comprising lactating women residing in Shanghai in the first 6 wk after delivery. The Chinese postnatal confinement diet, known as 坐月子 (*zuò yuè zi*), aims to nourish the mother while promoting the production and quality of breast milk. The specifics of the confinement diet differ within China depending on the region and cultural practices. Common recommendations include increased food quantity, avoidance of cold foods (e.g., vegetables and fruits), and high intakes of protein-rich foods (e.g., pork, chicken, fish, and eggs) and other hot foods (e.g., rice, ginger, and sesame oil) [14,24]. In urban regions like Shanghai, the *zuò yuè zi* is often modified under the influence of globalization and modernization. It is known that urban residents are more likely than rural residents to deviate from traditional diets [25], demonstrated in this study by, for example, the inclusion of cold foods such as vegetables and fruits in the confinement diet. Additionally, the various studies have applied different categorization of foods into food groups, which makes it difficult to compare dietary patterns.

In the present study, participants who scored high on the high-in-eggs pattern were found to have characteristics that matched with a lower socioeconomic status. The high egg intake in this dietary pattern may be associated with high(er) adherence to the more traditional confinement diet, in which eggs are considered highly nutritious when food accessibility is relatively limited. Participants who scored high on the high-in-animal-foods (high intakes of oils, vegetables, meat/poultry, grains, beans, milk/dairy, and fish/shrimp, and low intake of fruits) and high-in-plant-foods (high intakes of tubers, vegetables, and milk/dairy, and low consumption of grain, eggs, and meat/poultry) patterns were found to have characteristics that matched with having a higher socioeconomic status—that is, a higher percentage of participants in the higher income categories and a larger house size. Participants in the highest tertiles of these patterns more easily met required levels of nutrients than those who scored high on the other dietary patterns.

Moreover, participants who scored high on the high-in-animal-foods and high-in-plant-foods patterns had higher concentrations of fat and carbohydrates, and lower concentrations of protein, in colostrum.

The finding that a diet with high maternal intakes of oils, meat/poultry, and milk/dairy—that is, foods high in protein and fat—positively correlates with total fat content in colostrum is in line with previous findings [9,26]. Protein concentrations in HM have been suggested to be more resistant to variations in maternal intake [8,10,11]. Here we report that a diet high in protein is related to lower protein concentrations in colostrum. This finding is in contrast with the majority of studies in the field, showing either no effect of maternal protein intake on protein concentrations in HM or a positive association [8,10]. Yet those studies were done with mature milk, whereas—as also suggested by the present study—effects may be more pronounced in colostrum. The higher protein content in colostrum compared to mature milk [27], as well as the lower total secreted volume [10,27] and more predominant paracellular pathway of milk secretion in early lactation compared to late lactation, may be responsible for the observed differences between colostrum and mature milk [10,28,29]. Notwithstanding the fact that lactose has previously been reported to be the macronutrient in human milk that is least affected by maternal diet [10,12], we found that the high-in-animal-foods and high-in-plant-foods dietary patterns were positively associated with carbohydrate content in colostrum. Although the free carbohydrate content in HM as measured by the Miris system predominantly consists of lactose, oligosaccharides are another significant source of carbohydrates, comprising about 25% of the free carbohydrates in HM [30]. It has been hypothesized that maternal diet influences HM oligosaccharide concentrations [31], but more studies are needed to elucidate any association between them.

We found that estimates of the multivariable models obtained with or without adjustment for energy were largely similar, indicating that maternal dietary energy intake is not a significant predictor of HM macronutrient content. This finding is in line with previous literature [26,32,33].

Strengths of this study include the fact that we measured dietary intake and HM composition at various time points during the first 52 d postpartum, which allowed us to explore their stability in the first 2 mo of lactation and provided very robust data on both. The thorough prospective dietary assessment, using up to three 1-d food records combined with photographic records, enhanced the accuracy of the dietary-intake reporting. Moreover, HM storage and analysis for macronutrients were carried out according to a detailed protocol and standard operating procedures. Furthermore, we applied multivariable statistical techniques that consider correlations and interactions between multiple components in the diet. With this approach, potential synergistic or cumulative effects of multiple nutrients were taken into consideration, and multiple-comparison problems and confounding by other dietary components were diminished.

Yet as a limitation of this study, the HM analyses did not include micronutrient analysis. Other limitations include the lack of information regarding use of vitamin or mineral supplements, which may be used by a considerable number of women during lactation. Moreover, the China Food Composition Book does not contain (complete) information for iodine, vitamin D, folate, and ω -3 fatty acids, and therefore these essential nutrients during lactation could not be analyzed. Furthermore, our findings may be subject to residual confounding. We found that participants in the MCC group who had a higher socioeconomic status [14] generally scored higher on the high-in-animal-foods dietary pattern, whereas those in the Community group who had a lower socioeconomic status generally scored higher on the high-in-eggs pattern. Hence, we cannot rule out the possibility that the differences in HM composition between the dietary patterns are a result of

other factors (not dietary intake) related to socioeconomic status. Our small sample size (122 lactating women) is another limitation of our study, as it is too small to accurately represent the population of lactating women in China, thereby limiting the generalizability of our findings. But it does provide an 80% chance of detecting, at $\alpha = 5\%$, that a relationship between dietary pattern and HM macronutrients with a correlation coefficient of 0.25 differs from zero [34,35]. Moreover, Hu et al. [36] investigated the reproducibility and validity of dietary patterns identified with a similar small sample size and method, and concluded that they were reasonable. Lastly, a key limitation is that this is an observational study; therefore, it is not possible to draw any conclusions on causality. In this study we establish merely correlations, not causality. Future studies should aim at examining the causality of our findings by using longitudinal (repeated-measures) experimental designs, including also the period after the puerperium.

Conclusions

This is one of the few studies to provide quantitative evidence of the associations between maternal diet and HM macronutrient composition in the puerperium. The use of principal component analysis provided insights into dietary-intake patterns of Chinese lactating women and their association with HM macronutrients, and may be more predictive of HM composition than single foods or nutrients. We found that dietary patterns with high proportions of animal (meat/poultry, fish/shrimp, milk/dairy) and plant-based foods (tubers, vegetables, and beans) were associated with higher fat and lower protein concentrations in colostrum. In mature milk, dietary patterns high in animal foods were positively associated with carbohydrates, and those high in plant-based foods were negatively associated with fat.

In conclusion, this study provided a solid and valuable basis to further explore associations between diet and HM composition beyond a more individual ingredient level. Further research is needed to better understand the functional implications of this on infants' health.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2021.111392.

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