HOUSEHOLD FOOD INSECURITY ASSESSED BY THE FOOD ACCESS SURVEY TOOL (FAST) IN RURAL BANGLADESH AND MATERNAL AND INFANT NUTRITIONAL OUTCOMES

by
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ABSTRACT

Background: Food security is a major concern in South Asia, where it coexists with the highest prevalence of maternal and child malnutrition in the world. The goal of this research was to investigate associations between household food insecurity (HFI), measured on a behavior-based scale, and both maternal diet and nutritional status during pregnancy and lactation and infant growth to 6 months of age in rural Bangladesh.

Methods: Subjects were enrolled from November 2009 to June 2011 into a large cluster-randomized prenatal supplementation trial. Prospective dietary and nutritional status data from a cohort of 18,841 mothers and infants were collected from early pregnancy to 6 months postpartum. HFI was assessed using a 9-item Food Access Survey Tool (FAST), from which validity of using a summative index of its scores to reflect latent HFI was first established. Multivariate linear regression models of HFI, adjusting for maternal and household factors, were performed to explain associated variation in a) maternal dietary diversity, b) change in maternal weight and mid-upper arm circumference (MUAC) in pregnancy and lactation, and c) infant size at 6 months of age.

Results: Half of the households were food insecure. The HFI index was dose-responsively associated with poorer antenatal and early postnatal dietary quality, especially reduced consumption in animal-source foods. While maternal size early in pregnancy and seasonality were strongly associated with the level of HFI, changes in neither maternal weight nor MUAC during pregnancy and lactation were correlated with HFI status. With poorer HFI, infant sizes at 6 months decreased progressively. Maternal nutrition at 1st trimester and infant size at birth together explained 57-89% of the infant size deficits associated with HFI at six months. Postnatal feeding, morbidity, and socio-economic status accounted for less than a third of the variability in infant size at 6 month explained by HFI.

Conclusions: Widespread food insecurity persists in rural Bangladesh. In a large materno-infant cohort, we found evidence supporting strong and persistent nutritional consequences of food insecurity. Policies that address both food insecurity and reduce maternal and infant malnutrition should focus in women early in, and likely long before, pregnancy.

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ACRONYMS

1MP	1 month postpartum
1TM	1st trimester
3MP	3 month postpartum
3TM	3rd trimester
6MP	6 month postpartum
95%CI	95% Confidence Interval
BMI	Body mass index
BMR	Basal metabolic rate
CC	Chest circumference
DGLV	Dark green leafy vegetables
DHS	Demographic and health Survey
FANTA	The Food and Nutrition Technical Assistance group
FAST	Food Access Survey Tool
FFQ	Food frequency questionnaire
GA	Gestational age
GHI	Global Hunger Index
GRM	Graded response modeling
HAZ	Height-for-age z scores
HC	Head circumference
HFI	Household food insecurity
HFIAS	Household Food Insecurity Access Scale
HFII	Household food insecurity index
IDA	Iron deficiency anemia
IRT	Item response theory
JCUF	JiVitA Cohort Update Form
LAZ	Length-for-age Z-score
LMIC	Low and middle-income countries
LMP	Last menstrual period
MINIMat	Maternal and Infant Nutrition Intervention in Matlab study
MUAC	Mid-upper arm circumference
OR	Odds ratio
PI	Ponderal index
SES	Socio-economic status
SI2	Summative index of 2-items on FAST
SI9	Summative index of 9-items on FAST
US-HFSSM	Household Food Security Survey Module developed by US Department of Agriculture
VAFV	Vitamin A-rich fruit and vegetables

WAZ	Weight-for-age Z-score
WDDS	Women's dietary diversity score
WHO	World Health Organization
WHZ	Weight-for-Height Z-score
WI	Wealth index
WLZ	Weight-for-length Z-score

CHAPTER 1: Introduction

Food insecurity is a major concern in rural South Asia. Worldwide, about 870 million people were estimated to be insufficient in dietary energy in the period 2010-2012 (1). The largest fraction, 304 million or 35% of the food insecure, is living in Southern Asia (1). In parallel with endemic food insecurity in South Asia is a high prevalence of maternal and child malnutrition. Maternal undernutrition, defined as a body mass index (BMI) lower than 18.5 kg/m^2, has remained stable and high since the 1980s, affecting 15% women of reproductive age in the region (2). Thirty-six percent, or 69 million children, were noted to be stunted in this part of the world in 2011 (2). Among most affected groups are women and children living in rural Bangladesh where, based on demographic data from 2011 (3), 28% of women aged 15-49 years are undernourished ($BMI<18.5\ kg/m^2$), and 43%, 16%, and 39% of preschoolers are stunted, wasted and underweight, respectively.

To date, evidence has accumulated to link household food insecurity (HFI) with poorer dietary intakes among non-pregnant, non-lactating women (4-7) and growth faltering among children under five (8-11). However, only a few studies have focused to date on how HFI may affect diet and nutritional status of women during pregnancy and lactation (12). Also inadequately understood are the pathways and time windows during which HFI may reduce child growth. A multi-country study that included a site in Bangladesh recently revealed strong associations between HFI and stunting and underweight status among preschoolers; however, differences in recent dietary intake failed to mediate these effects in each of the three studied countries (13). Lack of apparent dietary mediation suggests that HFI may exert its effects on child growth through other pathways, including altered feeding practices (14-16), and increased morbidity (17, 18), and raises the prospect of a far longer-term pathway beyond the period of recall about food insecurity, extending potentially to maternal-fetal pathways (19-23), assuming HFI persists for years.

The JiVitA-3 project (24) is a large cluster-randomized prenatal supplementation trial in rural northeastern Bangladesh, which assessed HFI using a behavior-based scale and prospectively followed 18,841 mother-infant dyads to assess their dietary and anthropometry measures from early pregnancy to 6 month postpartum. The JiVitA study area has been shown to reflect characteristics typical of rural Bangladesh. Further, the JiVitA-3 trial has provided a unique opportunity to explore HFI and its relation to food consumption and maternal nutritional status during gestation and lactation, and how these dynamics may be affecting infant growth. This cohort, with assessments of maternal size, infant growth from birth to 6 months of age, postnatal feeding practices and child morbidity also allowed examination of different pathways linking HFI to early infancy malnutrition.

The findings of this longitudinal study provide new knowledge on likely mechanisms by which maternal and child malnutrition may be affected by chronic food insecurity. Studies such as this one, that attempt to disentangle the complexity by which the household food environment, as perceived by mothers in their responses to questions about food-related stress, may affect infant growth may help reveal patterns that could, in the future, be addressed by policies aiming to both improve household food security and reduce the high prevalence of childhood malnutrition in South Asia.

Specific Aims

Specific Aim 1: To explore the association between household food insecurity and maternal dietary quality during pregnancy and lactation.

Hypothesis 1a: Household food insecurity is inversely associated with antenatal and postnatal maternal dietary diversity;

Hypothesis 1b: Household food insecurity is inversely associated with the odds of mothers consuming animal-source foods during pregnancy and lactation.

Specific Aim 2: To examine the relation of household food insecurity and maternal nutritional status during pregnancy and lactation.

Hypothesis 2a: Household food insecurity is inversely associated with maternal height, weight, mid-upper arm circumference (MUAC) and positively associated with the risk of undernutrition in pregnancy and during postpartum period.

Hypothesis 2b: Household food insecurity is associated with less gestational weight and MUAC gains and greater losses in weight and MUAC during lactation.

Specific Aim 3: To study the pathways linking household food insecurity, maternal nutrition and infant growth at 6 month of age

Hypothesis 3a: Household food insecurity is inversely associated with birth size and infant size at 6 months;

Hypothesis 3b: Household food insecurity is positively associated with infant's risk of stunting, wasting, and undernutrition at 6 months;

Hypothesis 3c: The association between household food insecurity and infant size at 6 months is mediated through a maternal-fetal nutritional pathway.

Organization of Dissertation

This dissertation composes eight individual chapters. Chapter 1 gives an overall introduction and the specific aims. Chapter 2 reviews the food insecurity concept, measurement using behavior-based scales, risk factors and nutritional consequences associated with household food insecurity. After building the background, Chapter 3 introduces the study context, structure and data collection in rural Bangladesh and methods used in statistical analysis. Chapter 4 provides statistical evidence of the validity of using a simple summative index from the Food Access Survey Tool (FAST), followed by a brief description of the external validity and dependability of FAST in our study area. Chapter 5, 6, and 7 present three research papers, each addressing one of the specific aims. Keeping household food insecurity as the primary exposure of interest, Chapter 5 and 6 explores antenatal and postpartum maternal diet and nutritional status as a potential practice and state of health that covary with HFI. Chapter 7 focuses infant growth outcomes at 6 months of age in relation to food security of households. The final chapter summarizes key findings, implications, strengths and limitations of this dissertation, and offers suggestions for future studies. Supplemental documents are located in appendix for reader's reference.

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CHAPTER 2: Literature Review

The Concept of Household Food Security

Food security is a multi-fold concept that was gradually recognized during the past four decades from 1974 to 2001 (**Table 2.1**). The initial definition put food production in the central position for ensuring global food consumption (1). Food access was later recognized as a key component for food security because low purchasing power, lack of transportation to local market, and poor community infrastructure are additional barriers to food acquisition by vulnerable people regardless the status of food production (2). Layers of complexity including health consequences (3), food safety and food preferences (4) were added to this concept in later global conferences. Currently, to balance comprehensiveness and simplicity, the Food and Agriculture Organization of the United Nations defines food security as a situation that "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (5).

The definition has emphasized three dimensions of food security: a) availability, a measure of how food is available in the relevant vicinity of the household unit; b) access, a measure of the household's ability to acquire available food, financially, physically and socially; and c) utilization, a measure of how the household makes use of the food in terms of food allocation within the unit, as well as food preparation and consumption among different members. The three pillars of food security concept, food availability, access and utilization, are intrinsically ordered in a hierarchy (**Figure 2.1**) (6).

Measuring Household Food Access Using Behavior-based Scales

Rationale

Among the three dimensions of the food security concept, food availability, food access, food utilization, there are widely accepted proxies for the first and the third aspect (6). However, food access is a latent concept, which lacks direct measurable indicators. Rather, the severity of household food access stress is likely reflected by some identifiable "symptoms", which are the nature, frequency and intensity of the coping behaviors that the households adopt under household food access insecurity (7). The reason that the coping behaviors can reflect severity is rooted in the idea that food insecurity and hunger are "managed processes" (8), meaning that perceptions and behaviors evolve with progressive difficulty in food access. Anxiety over food acquisition happens first when the family senses the threats and constraints to food acquiring. Then, households may adopt strategies to cope with real food scarcity, starting with compromising diet quality by eating cheaper and less nutritious food to maximize calorie requirement. Reduction in food quantity follows when food insecurity is more severe. The basic idea of behavior-based scales is to order households along a food insecurity continuum based on a range of displayed behavior symptoms (9).

Development of behavior-based food access scales

The first behavior-based module is the Household Food Security Survey Module (US-HFSSM) developed by US Department of Agriculture (10) (**Table 2.2**). The core scale is a 10-item three-stage design scale with 3 questions about overall household food access situation, 5 questions about adults' coping strategies and perceptions when facing milder food insecurity and another 2 questions related to adults' coping behavior related to moderate and severe food insecure scenarios. It identifies key domains of experiences along the severity of food insecurity (access): uncertainty and worry, inadequate quality, insufficient quantity and hunger and physical consequences (11). The module has been modified, adapted and validated in many developing countries where a local scale was not available (12-14). It is also used as a model to develop culture-specific scales in later researches.

There are currently three scales that were designed to measure food insecurity (access) in Bangladesh: the Food Access Survey Tool (FAST) by the Food and Nutrition Technical Assistance (FANTA) group (15), the Household Food Security Scale created by the Maternal and Infant Nutrition Intervention in Matlab study (MINIMat scale) (16), and the Household Food Insecurity Access Scale (HFIAS), also created by the FANTA group to measure food insecurity across different countries (17, 18). Both the FAST and the MINIMat scale have added the domain of social acceptability in food acquisition because coping behaviors, such as borrowing food and taking food for credit are commonly applied for food augmentation in Bangladesh when the family is food insecure (16, 19). The cultural-specific coping behaviors are likely to happen in line with the other common domains of coping behaviors (20). The HFIAS dropped the social acceptability domain because it is hard to develop a set of questions that represents universal resource augmentation strategies across different cultures (17). Regardless of their differences, all behavior-based food insecurity (access) scales share commonality in their short-length nature (9-11 questions) and their ability to cover multiple key domains that represent the underlying progressive stages of food insecurity (**Table 2.2**).

Validity of behavior-based food access scales

Validity is an important concern before any measurement tool is implemented. Because food insecurity is a latent variable that cannot be measured directly, there is a lack of "gold standard" to be used for validation. Its validity criteria have some special considerations: well-grounded construction, performance consistent with understanding, precision, dependability, and accuracy and attribution of accuracy (21).

Well-grounded construction refers to the good construct validity of a scale (22), that is, whether or not the experiences asked in the scale can be interpreted in the theoretical food insecurity concept and domains. *Performance consistent with understanding* indicates item response patterns are consistent with expected behavior and trends. In other words, the understanding of the scale by respondents should be in line with developer's intention and the response pattern should reflect the severity of the underlying food insecurity status. *Precision* refers to the reliability of the scale in measuring food insecurity; that is, how much repeated measurements converge to each other. *Dependability* refers to whether changes in comparator measurements, such as potential determinants and consequences, are reflected in the differences in scale responses over longitudinal measurements. *Accuracy* is that the scale is unbiased in measuring food insecurity. Because there is a lack of "golden-standard" indicator measuring the true household food insecurity, the next definitive measure would be to compare the scale score with categorization consensus made by qualitative research. Additional evidence for accuracy would from comparing measures from scale responses with tangible indicators of the determinants and consequences related to insufficient food accessibility. Association in expected directions between scale measures and definitive indicators would support a good accuracy of the scale. *Attribution of accuracy* examines the hierarchy of relationships between multiple determinants, outcomes and the food insecurity being measured by the scale. The measure from an accurate food access scale is expected to add more information beyond what determinants could capture. The validity of FAST, which is being used in this dissertation research, will be discussed in Chapter 4 in more detail.

Risk Factors Associated with Household Food Access

As discussed in the previous session, sufficient food availability is a prerequisite for sufficient food access. Factors related to overall food availability are discussed first for a general understanding of food sources and the food system, with a focus on Bangladesh. Risk factors predicting food access at household level are then discussed by three means with which households acquire food identified by FAO in the food security definition: physical access, economic access and social access (5).

Food Availability

Food availability is a prior necessity for sufficient food access (6). Per capita dietary energy supply is used as an indicator for food availability (23, 24). Using an indicator of average dietary energy supply adequacy, expressed as dietary energy supply as a percentage of average dietary energy requirement in each region/ country (**Figure 2.2A**), the majority of the world, including the least developed regions, managed to supply adequate calories to meet energy requirements, assuming even distribution. The success in feeding the fast-growing population is a remarkable achievement of the Green Revolution, which introduced high-yielding crop seeds and agricultural techniques to farmers. In developing countries including South Asian countries, cereal production more than doubled from 1965 to 1999, at a rate faster than population growth in the same period of time (25). In fact, plant-based diets provided more than 60% of the energy and ~45 g/ capita/ day protein in poor settings (figure 2.2A and B). In Bangladesh, a cereal-based diet is even more dominant, providing about 80% of the energy on average, with protein from animal-sourced food being very limited (figure 2.2B).

Bangladesh is an agriculture-centered country. Out of the land area of ~13,000 km^2, 70% is used as agriculture area (26). Rice is the major cereal crop with steady growth in production over the past 20 years and stays in the essential position in the diet (27). Based on the most updated national Household Income and Expenditure Survey, in rural Bangladesh rice accounts for about 40% of household food expenditures (28) and about 63% of caloric intake (calculated based on data from (28) and (29)). Rice cultivation dominates total cropping land area by 74%, followed by wheat for ~5%. The rest of ~11% land is cropped with other foods, such as pulse, fruits, oilseeds and vegetables (27, 30).

Because of the geography and tropical climate of Bangladesh, cropping is predominately monsoon dependent and displays seasonal patterns (**Figure 2.3**). Therefore, food supply varies by season. There are two agricultural seasons: the high-temperature and humid *Kharif* season from April to November, and the dry sunny *Rabi* season from November to March. The three major groups of rice, *Aus*, *aman* and *boro* are cultivated throughout the year, with *Aus* and *aman* being the rainfed rice and *boro* as the irrigated rice. Typical crops grown in the Kharif and Rabi seasons are listed in **Table 2.3**. In summary, food is more available during harvest seasons after the major *aman* rice harvest and is particularly scarce during preharvest period of *aman* rice, lasting from mid-September to November (known as lean season or *Monga* in local term), and in the period prior to the harvest of boro rice from mid-March to mid-April (known as *Little Monga* in local term) (31) (figure 2.3).

Other than seasonality, food availability is also a function of the entire food system, including food production, imports and exports, storage and distribution. The importance of such factors along the chain from farm to table is well recognized; however the complexity of food system is out of the scope of this dissertation study. Because our study population is located in a rural setting in an area of the same administrative district, the study area is unlikely to be extremely heterogeneous in terms of the factors listed above.

Physical Access

Physical food access refers to food availability within the physical reach of households (32). Physical food access can be ensured through household production and/or through food market. Household food production is determined by the household entitlement that can be used for food production, such as land, irrigation facility, labor, etc (33). Common physical barriers for food acquirement from market include poor infrastructure, inadequate logistics for food distribution and market imperfections (34). The two sources of physical food access are discussed in greater detail separately.

Homestead Food Production

Ownership of homestead gardens and access to animals provide direct physical access to food from household production. In South Asia, homestead gardening and animal husbandry, varying in size and biodiversity, are traditional food producing practices and supplement the accessibility to more nutritious and diverse diet for the poor (35). For example, in an observational study in Nepal (36), the size of the home garden was associated with overall fruit and vegetable consumption and access to domesticated animals was associated with increased consumption of animal-sourced food, such as milk, meat, and eggs. In Bangladesh (34), 97.5% of vegetable consumption depended on market and other sources for households without any home garden. The percentage dropped to 3.2% for households with a developed garden that produces a variety of vegetables in fixed plots throughout the year. The variety and quantity of fruit and vegetables grown in home gardens has been shown to be an independent predictor of vitamin A intake among Bangladeshi women after accounting for socie-economic status (37). Other than observational studies, evidence has accumulated around the world (38-43) from intervention trials linking homestead gardening improvement programs with increased accessibility and consumption in fruit and vegetable at household and individual levels. Interventions aiming to promote animal-source food production, such as dairy, poultry, and fish, generally increase production and income (44, 45), which can be used to enhance economic access to food, yet the evidence was inconsistent (44, 45).

In summary, households with productive entitlements to produce food from gardens, ponds or husbandry practice have greater likelihood to enhance food security status, directly supplementing diet from household production or indirectly from generating additional income to purchase nutritious food elsewhere.

Market Access

When homestead food production is limited, the major food supply is from the market, especially for landless households (32) and low-income families (46). Two systematic reviews (47, 48) have reached consensus that in the US, where most studies were conducted, poor physical access to food stores, assessed as lower number of food retailers, further distance to supermarkets, and poorer quality of food provided, was disproportionally more common among disadvantaged groups, such as minorities and low income communities. In low-income countries, the role of well-developed rural infrastructure, for example, the access to paved road (49) and the existence of upgraded markets (50) have been conceptually identified as important factors for food security, though the relationship is rarely tested by data. One meta-analysis was conducted to summarize the determinants of food access and chronic food insecurity in southern Africa and poor market access was recognized as one of the most cited direct drivers of food insecurity among 49 qualified studies (51). In Bangladesh, for example, projects funded by the World Bank to improve rural road condition and infrastructural development of local markets saved more than half of the time to the nearest village market (52). The ease of access to markets not only increases food access from market but also expands agricultural production and exchange, which in turn helped generate 8-10% growth in household per capita consumption for food and nonfood products. In a previous analysis from our study area, Shamim et al (26) discovered a significant negative bivariate association between dietary diversity and distance to local food markets. Improved physical access to food markets has a more pronounced effect on consumption when the households are geographically isolated. In Nepali remote villages, longer travel time to the nearest market is significantly associated with perceived food adequacy even after controlling for household characteristics such as education, unemployment, illness and district rainfall (53). However, mixed findings have been shown on the relationship between physical distance to food stores and perceived food insecurity status in other studies from

North America (54). The mixed results indicate that physical access to places of food procurement is only one of many factors related to the overall food access and security and may not play an equal role under different cultural context and food environment.

Economic Access

As Sen recognized in his famous entitlement approach for starvation analysis (33), “a person’s ability to avoid starvation will depend both on his ownership and on the exchange entitlement mapping that he faces”. Internally, household characteristics determine how much of the entitled resources are available for food purchasing, that is, the ownership entitlement potentially used for food exchange. Externally, the economic environment defines the rules for exchanging household entitlements for different combinations of commodities including food. In this section, Sen’s entitlement approach will be incorporated in the discussion of economic access to food.

Household entitlement ownership

At the household level, entitlement ownership for food exchange can be categorized into three broad groups (25, 33): agricultural productive resources, labor power and ownership over other resources. Agricultural productive resources comprise the household endowment to exchange food with nature. Food produced can either be consumed directly (physical food access, discussed in the previous session) or be sold for cash (economic access). Labor power is the human capital endowment to exchange labor for wages (economic access), and ownership over other resources, such as durable assets, is an asset endowment for cash exchange, i.e. sale (potential economic access).

Empirical data has shown the ecological relationship between lower economic level and food insecurity. In the US, there is a clear relationship between increased income and decreased proportion of hunger and food insecurity; households with income less than the poverty level are 3.5 times more likely to experience food insufficiency compared to households with income above the poverty threshold (55). In developing countries, a similar relationship was demonstrated by the negative association between the gross national income per capita against the Global Hunger Index (GHI), a composite indicator for the prevalence of malnutrition from 120 low-middle income countries (56).

At the household level, the indicators for economic access and food insecurity are also tightly connected. For example, reduced total household food expenditure was associated with increased severity of perceived food insecurity in Bolivia, Burkina and the Philippines (57). In Bangladesh, greater freedom for women participating in income-generating activity among indigenous non-Muslim groups enhanced economic access to food for female-headed households in Chittagong Hill area (58). A shortfall in a household's entitlement may put the family at risk of food insecurity because their reduced total endowments may no longer be sufficient to exchange for the required food (33). In Bangladesh (59) and Cambodia (60), less ownership of durable assets predicted higher risk of child nutrition insecurity such as stunting.

Under economic limits, a household faces competing needs for food versus non-food expenses, such as health care, housing and other goods (25, 61). An interesting example is seen in the expenditure competition between tobacco and food, a potential mechanism leading to increased food insecurity among households with smokers (62, 63). Smoking prevalence among the poorest Bangladeshi households is 58.2%, which is the higher than any other socio-economic groups (64). Smoking behavior could impact household food security because, based on estimation by Efroymson et al (64), the money spent by the poor male smoker could have been exchanged for 1400 calories worth of rice per day, equivalent to 1.3 times calories as required for a 3-y old child or almost half of the daily calorie required for adult males.

Exchange Entitlement Mapping

Households make daily expenditure decisions given their income exchanged from agricultural resources, labor, or other assets, as well as under the complex “exchange entitlement mapping”, which is referred by Sen as the rules for commodity (33). In the case of food procurement when the relative price of food increased, the exchange entitlement system switches to a less favorable condition for food exchange, putting households with equal entitlement ownership at higher risk of food insecurity (33).

One good example to demonstrate the power of shifts in exchange entitlement mapping is to examine food exchange behavior under food crisis, which is intensively studied in the food security literature. In the recent Bangladeshi food crisis in 2008, the rice price had increased by 24% in January 2009 compared to the price in late 2006 (65). Daily wage-to-rice purchasing power had reduced by about 2 kg from mid-2007 to mid-2008 (65). The price of non-staple food increased at even higher rate during food crisis (25). As a result, staple food appears to be more affordable compared with non-staple food. It is estimated that in Bangladesh households would increase expenditure on staples by 43% and reduce expenditure on non-staple foods by 29% if facing price hikes of 50% when holding income level constant (25). This simulated estimation is consistent with empirical data (65-67), which observed reduced food quality and quantity being consumed during crisis, characterized by a greater share of energy intake from staples and less from animals, fish, and other non-staple vegetables and fruits. Data has indicated a positive relationship between frequency and intensity of coping behaviors and the occurrence of food crisis. Comparing household food insecurity scores before and after the 2008 crisis, the proportion of household food insecurity as assessed by HFIAS increased from 12% to 36% (68, 69).

It should be emphasized that the impact of food crisis observed above possibly has mixture effects on both changes in exchange entitlement mapping and household entitlement ownership, though it is often hard to partition the two from each other. For example, food crisis affects income generation activity in a disproportional way: some agricultural producers may benefit from food price increases (25). However, small scale farmers are not likely to be the beneficiaries due to their limited productivity, disadvantaged bargaining position and lack of information (68, 70). It is also expected that households use entitlement ownership as a buffer to trade for food in case of food crisis (66, 68). Under certain conditions, people could sell entitlement bundles, trading off short-term consumption needs against longer-term economic viability (71, 72).

Social Access

Intra-household: gender specific roles in social food access

Bangladeshi men and women play different social roles in maintaining household food security inside the same household (73). As part of the rural culture, it is generally women's business to prepare and give food gifts and borrow food from kin and neighbors in the vicinity of the household; men are responsible for borrowing food elsewhere, borrowing money, taking shop credit from the market, and taking food loans through their social network and personal relationships. Because of the different social roles in resource augmentation activities, males and females from the same household respond differently when asked about the experiences of social food access. For example in the Bangladesh Food Insecurity Measurement and Validation Study (74), 42% sampled men, but only 21% women, had reported taking food on credit from a local shop in the past 12 months. The percentage of men and women who reported ever borrowing food from neighbors in the past year was 31% and 13%, respectively. Though food gift is one common way to acquire food in South Asia (75), social access by food gift seems only to supplement food sources. Gifts given, both in the form of food and nonfood, take 0.1 to 0.5% of the expenditure budget in rural Bangladesh (76). In a Bangladeshi urban slum only 30% households received gift or loan in the past month and it was not a significant contributor to household food security in terms of calorie consumption or food quality (77).

Because of the separate domains of food-related responsibilities, female-headed households may be more vulnerable to the lack of social food access, in addition to the their “triple burdens” of poverty (78, 79), which are to be “income poor” because of gender inequality in the labor market, to be “time poor” because of responsibility in household chores, and to have “low purchasing power” because of higher dependency ratio for being single income earner.

Inter-household: social capital and social support

In many low-income countries, rural people live in closely knit communities and rely on support from their neighborhood to enhance food security. Social capital, a measure of social trust and community reciprocity, can ease the accessibility to help and resources for food-insecure households, for example, to get food credit and pay later, to borrow food or to borrow transportation means from neighbors to get to a food market. A book (80) introducing the concept and measurement of social capital by the World Bank included a study on determinants of social capital in Bangladesh. It found that the share of households with a business and the share of residents that own their home were positively and significantly associated with social trust, reciprocity and sharing, the three relevant aspects of social capital. Data from the US Social Capital Community Benchmark Survey in 2000 (81) provided an opportunity to examine determinants from a large sample of wide demographic and geographic diversity (n=24,384). Respondent's individual socio-demographic factors, including higher education attainment, employment, and older age, as well as household and community indicators, including higher household income, house ownership, rural residency, and less ethnic diversity were independently and significantly associated with higher perceived social capital. Data from rural Bangladesh is not found, yet it is known that vertical redistribution of goods and services from the local wealthier to the poorer is a traditional practice in the rural Bangladeshi moral economy (82).

There are inconsistent findings when linking social capital with the responses on behavior-based food security scales. Using a validated Likert questionnaire, social capital was first measured at the household level and then aggregated at community level (83). Martin et al reported that a higher community social capital halved the probability of a household to experience hunger (adjusted OR=0.47, 95%CI: 0.28-0.81) measured by the 18-item US-HFSSM, adjusting for demographic factors, including income, education, ethnic groups (84). Similar findings were also obtained by Brisson et al (85) and Dean et al (86) using slightly different methods. Non-significant results were found when more household characteristics were controlled in the model (87) or using single item instead of the entire scale to measure household food insecurity (88). Possible explanations of inconsistency results may be diverse community structures and disproportional effect of social support towards households with different socioeconomic status. For example, ultra-poor households living with shame and weak social networks are often out of the reach of social protection (82, 89, 90).

Social safety nets: credit, cash, or in-kind transferring programs

Social safety nets are programs that provide transfers, in the form of credit, cash or in-kind such as food, to augment income and to enhance livelihood among low-income households (91). Microcredit programs, providing small loans to the poor and sometimes combined with noncredit services, were innovatively modeled by Grameen Bank in Bangladesh and have been replicated in many countries. Leroy et al (92) summarized evidence of microcredit programs' impacton food security worldwide, including two projects conducted in Bangladesh. Microcredit participation by women, but not men, along with noncredit services (e.g. skill development training, behavior-changing training, etc.) was associated with: a) increase in food and non-food expenditure (out of 100 taka credit, 11.3 taka used for food, 21.0 taka used for non-food); b) increased arm circumferences of children age 15 years or younger; and even c) increased per capita total expenditure of nonparticipants in the same areas, possibly through strengthened informal social supports. Cash transfers, either conditioned to promote certain services or unconditioned, are likely to reduce poverty and improve household food security through enhanced economic access (91, 92). When food is distributed directly as in-kind transfer, the program impact on nutritional status seems to depend on the type of food provided, age group and initial nutritional status of beneficiary, and the degree of program compliance and sharing (93-95).

Summary

A conceptual framework is developed to summarize the interrelationship between the predictors of physical, economic, and social access to the overall household food accessibility (**Figure 2.4**). Food access insecurity is a complex concept. There are multiple factors predicting food accessibility at the household level, which are identified as independent factors and/or asfactors acting interactively under the economic access domain . From the next section on, we will refer food access insecurity as food insecurity for the sake of readability.

Nutritional Consequences Associated with Household Food Insecurity in Women and Young Children

Maternal and Children's Dietary Adequacy

The relationship between household food insecurity and individual energy and nutrient intake has been studied using the 24-hour recall method. It has been repeatedly found that perceived food insufficiency predicts lower energy among adults (96-98) and elderly individuals (99, 100). Adults living under food insecurity have a higher risk of being micronutrient inadequate (96, 101), though adults of different ages and sexes have differential risk, probably due to different intake patterns (96, 100). In other studies in which energy intake did not differ by food security status, an altered eating behavior was observed, such as reduced meal frequencies (102) and consumption of more snacks (102) or less fruits and vegetables (103) to maintain the same energy consumption level.

When 24-h recall data is not available, a food frequency questionnaire (FFQ) can instead be conducted to measure usual dietary intake (104). For measuring the typical South Asian diet, the FFQ is a validated method to represent usual dietary intake and quality compared with a repeated food dairy (105) or multiple 24-hour dietary recalls (106-108). High food quality indicates a variety of nutritious food. Women living under households with food insecurity, with or without hunger, have significant lower intakes in meat and animal-sourced food (61, 109-111) and fruits and vegetables (61, 103, 109, 111-114), which are more micronutrient-dense. Other than individual food group consumption, the dietary diversity score, which is the total number of food groups consumed by a household or an individual in a specific recall period, is commonly used to represent general food quality. The more diverse a diet, the higher food quality it has. There is an inverse association between dietary diversity and household food insecurity in the literature (115-119)(115).
Both food availability and economic access to food determine the variety of diet. A shift in the distribution of seasonal dietary diversity was found in Burkina Faso (115, 120) and Bangladesh (121), indicating the dietary adaptation of people to seasonal food sufficiency in many developing counties. In Bangladesh, household dietary diversity increased with per capita total food expenditure (122), with per capita total expenditure (122, 123) and less so with non-grain food expenditure (122).

Children's dietary intake seems to be less affected by household food insecurity. Much research examining the nutritional adequacy of children and adults in the same households failed to identify an insufficiency of energy (87, 96) or micronutrients (87, 101)among children as compared with recommended consumption levels. When comparing food intake of young children who are from food-insecure versus food-secure households, similar energy consumption was found in the US (124, 125), Canada (126), and Mexico (125); however, the way in which food insecure children managed to consume an equal amount of calories as their food secure counterparts was likely through different eating patterns and behaviors. For example, healthy eating index and healthy eating behavior, two indicators used to evaluate the healthiness of a child's diet, are lower for Canadian children residing in food insecure homes than their counterparts (126, 127).

One hypothesis to explain the discrepancy in consumption adequacy between moms and children is that the intra-household food allocation mechanism under food insecurity tends to protect younger children. In Bangladesh, regardless of food security status, rural women receive the last and smallest food shares during mealtimes (128). Facing food scarcity, Bangladeshi women are likely to compromise their own calorie intake (129, 130) and dietary diversity (25) to ensure adequate nutrition of their husbands and young offspring. Without this protection mechanism, the deterioration in child dietary diversity associated with increased severity of reported household food insecurity status in Bangladesh, Ethiopia, and Vietnam (131) might have been even worse.

It is also well-documented that intra-household food distribution favors boys over girls in rural Bangladesh. The differential food allocation by child sex could start as early as the postnatal period (132). Average energy intake of Bangladeshi weanlings was about 10 Kcal/kg/d greater in the harvest season from December to January than during the lean season from October to November (133). However, the benefit from improved food security due to season is disproportional by child sex (133): among children older than 18 mo of age, boys started catching up in calorie intake nearly two months earlier than girls and peaked at ~80kcal/kg/day in the harvest season, which is ~25kcal/kg/day more than the average peak of girls of the same age group in the harvest season. Appropriate infant feeding practices according to WHO/UNICEF recommendations leads to better child growth (134), but being a boy is associated with particular feeding behaviors provided by caregivers in rural Bangladesh (135). Specifically, Saha et al found that the infant feeding practice score calculated against the WHO/UNICEF feeding recommendation was worse for Bangladeshi girl infants in comparison with boy infants from the second half of infancy, after controlling for household food insecurity measured by the MINIMat scale, wealth, child morbidity and other infant maternal factors (136). Feeding practices seem less altered by infant sex prior to 6mo of age (136, 137), when breastfeeding is predominant and differential food distribution by child sex has likely not yet started.

Maternal Nutritional Status

There are inconsistent findings with regards to the association between food insecurity and adult nutritional status. Generally speaking, a spectrum of nutritional outcomes, ranging from underweight to obesity, is associated with food insecurity with increasing wealth level. Pooling nationally representative data from 37 low-income countries, Neuman et al (138) explores the relation between socioeconomic status, which predicts wealth and food security, and BMI. Per one quintile increase in wealth, there is a 0.7 unit increase in women's BMI (95%CI: 0.68-0.72) and a 22% increase in the risk of being overweight or obese (95%CI: 21%-23%). Therefore it is necessary to discuss the nutritional consequences associated with food insecurity under specific contexts.

In high-income countries, a relationship between reported household food insecurity and female overweight or obesity has been repeatedly seen (139-141). Women experiencing food insecurity had a three-fold risk of being severely obese prepregnancy (BMI>35.0, Adjusted OR=2.97, 95%CI: 1.44-6.14) and were more likely to gain greater weight during pregnancy compared with their food-secure counterparts (adjusted Δ=1.87kg, 95%CI: 0.13-3.62) (142). Similarly, Olson et al found that food insecure women in early pregnancy were at greatest risk of major weight gain, a weight gain equal to or greater than 4.55 kg, at 2 years postpartum compared to early pregnancy (143). The increased risk of being obese related to household food insecurity may be modified by race/ethnicity (144, 145), marital status (140) and food stamp program participation (146). The plausible hypothesized mechanisms are economic deprivation for healthy food in the households and overeating due to cyclical food purchases (146, 147). On the other hand, severe acute food quantity insecurity, such as the Dutch Famine, was associated with a substantial reduction in gestational weight gain comparing women exposed in the third trimester with those unexposed or only exposed in early pregnancy (148).

In poor countries, food insecurity is associated with higher risk of undernutrition, defined as women's body mass index (BMI) less than 18.5 kg/m^2. Better food security puts women at greater risk of overweight and obesity, defined as a BMI equal to or more than 25.0 kg/m^2. With an increased severity of food insecurity, the national prevalence of undernutrition in Bangladesh increased from 20% for women of food secure households to 39% of severe food insecure households; prevalence of overweight or obesity dropped from

20% to 8% (149). Campbell et al confirmed the association between the risk of maternal undernutrition and lower expenditures on non-rice food adjusting for potential confounders (150). Evidence suggests that Bangladeshi women's ponderal status, such as weight and MUAC, fluctuate with seasonal food insufficiency among non-pregnant women (151, 152) and among pregnant or lactating women (153). How gestational or postpartum nutritional status differs by chronic household food insecurity in developing countries, however, has not been examined.

In countries experiencing an economic transition where the double burden of child malnutrition and adult obesity coexist, the underlying nutrition transition returns mixed results. The poor continue struggling with basic food accessibility while the wealthy are affected by the more affordable calories in their increasingly obesogenic environment (91). For example, in Trinidad and Tobago, a middle-income country with a moderate high prevalence of undernutrition and obesity, food insecurity is found to be associated with a three-fold increased risk of underweight (OR=3.21, 95%CI: 1.17-8.81) but not obesity (OR=1.08, 95%CI: 0.55-2.12), adjusting for age, sex and ethnic group (113). Similar observations were found in Columbia (110), where food insecurity with severe hunger was associated with a two-fold increased risk (OR=2.0, 95%CI 1.0-4.0) in maternal underweight but was not associated with the risk of maternal overweight or obesity. However, in rural Malaysia, researchers observed a positive relationship between food insecurity and at-risk waist circumferences (≥88cm, OR=1.18, 95%CI: 1.02-2.54), even after adjusting for socio-demographic factors (117). In the National Demographic and Health Survey from Brazil, mild food insecurity, but not severe food insecurity, resulted in a nearly 50% increased risk of maternal obesity after accounting for income quartiles and other socio-demographic factors (adjusted OR=49%, 95%CI: 17-90%) (154). The inconsistent results from low-middle income countries may represent the fact that the various study populations are in different stages of the nutrition transition.

In summary, women from food insecure households are consistently prone to adverse nutritional outcomes via either: a) undernutrition for the poor who are struggling with food quantity insecurity in addition to food quality insecurity; b) overnutrition for the wealthier individuals in low-income countries who have begun to be affected by the poor quality of food in an obesogenic environment; or c) overweight or obesity among the disadvantaged groups in high-income countries who are consuming high-calorie, low-nutrient dense foods. Although behavior-based scales have been developed to rank populations according to the household food insecurity continuum, food insecurity problems vary largely from setting to setting (155). Researchers should therefore not compare scores from different settings even if the same scale is implemented (**Figure 2.5**).

Child Nutritional Status

The newly released Lancet series on maternal and child malnutrition (156) has revealed that one of every four children under five years of age is stunted; 165 million children are still affected by stunting. The statistic for wasting is 8.0% in terms of prevalence or 51.9 million in terms of number of children affected. The risk to malnutrition is disproportionally distributed across the globe and is notably more prevalent in South Asia and Sub-Saharan Africa, where food insecurity is also challenged. The poor and the hungry overlap largely in these two regions (157).

There is accumulating research on the association between coexisting food insecurity and preschooler malnutrition. Arimond and Ruel found a general positive dose-response association between dietary diversity scores and mean height-for-age Z-scores (HAZ) for children 6-23 mo old in 11 countries in which Demographic and Health Surveys were assessed, controlling for child age, maternal nutritional sizes, number of preschool-age children, household wealth and welfare factors (158). The association between better child dietary quality and risk of stunting also held true for children of different age groups, 6-11mo, 12-23mo and 24-59mo, in rural Bangladesh (159), which was not one of the 11 countries examined in the previous study. Assessing household food insecurity using the HFIAS from eight low-middle-income countries, 4 from South Asia, 2 from Sub-Saharan Africa and 2 from Latin America, Psaki et al (155) found that a 10-point increase in household access security score was associated with a 0.2 standard deviation decrease in HAZ among children under five, adjusting for a few factors at the household, maternal and child levels. Another multi-country study in Bangladesh, Ethiopia and Vietnam (131) and three other studies in Bangladesh (160), Pakistan (161) and Colombia (162) similarly identified positive associations between food insecurity and child stunting, yet insignificant results were also reported in Nepal (163) and Sri Lanka (164). Inconsistency in findings may be due to different age groups and different modeling strategies. A significant association between household food insecurity and child wasting was only reported in the Bangladeshi studies (131, 160). The risk of child wasting in relation to food insecurity in other countries was either not reported (161, 164) or found to be insignificant (131, 155, 162, 163). The missing association is likely explained by the distal connection between long-term food deprivation and the acute growth failure represented in wasting (165).

Few studies have examined the relationship between food security and biomarkers of nutritional status among preschool-age children. Two independent groups (166, 167) have analyzed data of two cross-sectional assessments from the Children's Sentinel Nutrition Assessment Program, which included food insecurity questions and hematological data of children less than 3 years of age in the US. Both studies consistently found a two-fold increase in iron deficiency anemia (IDA) for children living in food insecure households. A significant result was also seen among 3- to 5-year-old preschoolers (168), except that the risk for IDA was as high as ten-fold (OR=10.7, 95%CI: 1.5-76.9). None of the above studies have identified differential risk in iron deficiency according to household food insecurity status. Data from developing countries often did not include iron biomarkers. The level of hemoglobin of rural Indian children aged 12-23 mo increased with better socio-economic status (169). Increased risk of anemia was found among 6 mo to 5-year-old children in Indonesia (170) and Ethiopia (171) in food insecure households, adjusting for other known risk factors.

In summary, preschool-age children living in food insecure environments may have a higher risk of micronutrient deficiency and a higher risk of stunting and underweight. However, the pathway through which household food insecurity influences child growth remains largely unknown. A recently published study failed to find a mediation effect of child dietary diversity on the relationship between food insecurity and under-five child undernutrition in Bangladesh, Ethiopia and Vietnam (131), indicating the observed association may be attributed to factors that occur even before the child starts to eat household food and/or mechanisms that are independent of nutritional pathways.

Pathways Linking Household Food Insecurity, Maternal Nutrition and Early Infant Growth

Growth faltering pattern and risk factors for child malnutrition

Worldwide child growth patterns are studied using the World Health Organization (WHO) standards (172); using data from cross-sectional anthropometric surveys of 54 low-to middle-income countries, the mean weight-for-height z score (WHZ) was slightly above the standard (z=~0.12) in infants aged 1 to 2 months, then faltered slightly until 9 months of age. WAZ and HAZ started at 0.25 below the standard at 2 months of age and faltered moderately to about -0.75 at 9 months of age. From the 10^{th} month, WAZ kept dropping steadily to -1 z at 24 months, yet HAZ faltered dramatically until 2 years of age, reaching below -1.75 z. South Asian children had similar patterns of growth faltering but started at much lower z scores: for WHZ, WAZ and HAZ, it started at -0.75 z, -1 z and -0.75 z at 1 month of age, respectively (172).

The early onset of growth faltering indicates that the problem of undernutrition in South Asia originates from intrauterine retardation. Small for gestational age (SGA), defined as lower than the 10^{th} percentile for birth weight of gestational age, is a proxy measure for intrauterine growth restriction (173). In 2010, the prevalence of SGA was estimated to be 45% in South Asia, the highest among all low- to middle-income country (LMIC) regions (174). 65% of low-birth-weight births in South Asia were term SGA babies, indicating that being born too small rather than being born too soon is the major problem (174). Compared with children born term with adequate size-for-gestational age, children who were born SGA had a two-three-fold increased risk for stunting, wasting and underweight at 12-60 months of age and this level of risk remained approximately the same regardless of LMIC region (175). The lack of heterogeneity in the risk estimates of child malnutrition supported the idea of biologically plausible (175).

Poor maternal nutritional status predicts SGA. Recent meta-analyses have systematically reviewed the association between either pre-pregnancy underweight (176) or micronutrient status (177-180) and increased risk in SGA. Compared with normal-weight mothers, lower maternal BMI increased the risk of SGA by 81% (OR=1.81, 95%CI: 1.76-1.87) (176). Supplementing energy in pregnancy has the significant effect of reducing small for gestational age by a third (181). The odds ratio of SGA associated with low prenatal vitamin D levels was 1.52 (95%CI: 1.08-2.15) in one review defining low serum vitamin D as 25(OH)D<50 nmol/l (177) and similarly was 1.85 (95%CI: 1.52-2.26) in another review using a mixture of cutoffs for vitamin D insufficiency (178). However, prenatal supplementation with iron (179) or vitamin A or carotenoid alone (180), did not show a significant effect on SGA or preterm birth. Evidence from controlled trials have found that multiple micronutrients in pregnancy have a significant effect on reducing low birth weight by about 20% compared with placebo (RR=0.81, 95%CI: 0.73-0.91) or iron-folic acid supplementation (RR=0.83, 95%CI: 0.74-0.93), yet no significant reductions in preterm birth or SGA have been found among the 3 study groups (182). From the above evidence, micronutrient interventions may be necessary but may need to be combined with energy supplementation to improve fetal growth. Maternal older age, higher parity (183), smoking behaviors (184) and maternal depression (185) are identified as other biological or behavioral factors that are associated with intrauterine growth restriction.

After birth, food, disease and care are the key proximate factors determining child growth trajectory (186). Exclusive breastfeeding (in which only breast milk and oral rehydration therapy, drops and syrups are allowed) is recommended as the optimal feeding practice before 6 month of age (187). Breast milk alone is a good source of energy and nutrients for the first half of infancy, with the possible exception of micronutrient deficiencies in iron, zinc and certain vitamins (vitamin A, B6, B12, D and riboflavin), especially among lactating women with an inadequate diet (188, 188). Evidence from randomized controlled trials and quasi-experimental studies has shown that interventions focusing on breastfeeding promotion can significantly increase exclusive breastfeeding practices prior to 6 months of age (189). However, its efficacy on infant growth during the same period has been rarely examined, and available data indicate inconsistent results (190, 191). Infectious diseases, such as diarrhea, respiratory infections, malaria, measles, and tuberculosis, affect a large number of children in the developing world and can increase the risk of both acute and chronic child malnutrition (186, 192). Using data from cohort studies of multiple LMIC, diarrhea during the 1st month prior to anthropometric measurement was significantly associated with lower child weight from 6-20 months of age (193). Cumulative burden of diarrhea before 24 months was associated with smaller infant length (193) and increased odds of stunting at 24 months of age (194). Being exposed to unhygienic circumstances, children are more likely affected by frequent episodes of infections, which could sometimes be subclinical, known as disorder of the small intestine or tropical enteropathy (195). Tropical enteropathy is characterized with partial villus atrophy that reduces nutrient absorption, and damaged intestinal permeability, which induces translocation of macromolecules and triggers immune and inflammatory mechanisms (196). Both pathways explain the importance of sanitation and hygiene to infant growth.

Household food insecurity has long been recognized as one of the three underlying causes of maternal and child undernutrition (197). Perceived household food insecurity is associated with child undernutrition, but the plausible pathway that can explain the observed association is poorly understood. In rural South Asia, chronic food insecurity likely persists in poor households and therefore could influence young child growth through a number of pathways, namely the nutritional pathway linking maternal undernutrition with intra-uterine retardation, and postnatal pathways including altered feeding behavior and altered child care behavior. In the next section, each one of these pathways will be individually discussed.

The nutritional pathway

In poor settings, household food insecurity is associated with insufficient dietary adequacy and higher risk of undernutrition in women, as discussed in the previous section. Maternal nutritional status before and during pregnancy is not only a critical determinant of intrauterine growth (198-201), but also determines child postnatal growth (165, 175, 202-204). In pregnancy, the total energy cost is increased on average by 250-320MJ (205, 206), which is used to support the growth of new tissues in both the mother and fetus, the storage of maternal fat, and increased basal metabolic rate (BMR). Among affluent populations, recommendations have included to increase energy intake (207, 208) and nutrition density (208) in the diet to meet nutrition requirements. Evidence from controlled trials has found that supplementing energy (181) or micronutrients (182) in pregnancy has a significant effect of reducing small for gestational age by a third and reducing low birth weight by one fifth, respectively. Food insecurity in pregnancy unlikely provides sufficient micro- and, sometimes, macro- nutrients due to compromised food quality and/or quantity, which may lead to a greater risk of maternal micronutrient and/or energy deficiency, and consequently increased risk of adverse birth outcomes, such as low birth weight (209).

Under chronic food insecurity stress, energy adaptations in pregnancy may serve as a mechanism to protect fetal growth and birth outcomes; however, mixed findings exist. For example, BMR reduction was seen among Gambian pregnant women (205, 206) but was not evident among expecting women in Asia (210-213). Smaller proportion of fat deposition as initial weight (205, 214) serves as another energy-sparing mechanism. As a result, energy requirements during pregnancy could vary interpersonally given the differences in energy adaptations.

In lactation, energy demand is also increased for milk production. For exclusively breastfeeding mothers, the additional energy needs are estimated to be 595 kcal/day in the first two months of lactation and 670 kcal/day in the 3rd to 8th month of lactation (215). For partially breastfeeding women, the requirement is 553 kcal/day in the first 5 months of lactation (215). This additional energy requirement needs to be met from dietary intake, fat mobilization from reserves and potential energy-sparing strategies, including reduction in BMR and physical activities. The majority of evidence from both developed and developing countries indicates an unchanged or slightly increased BMR during lactation (212, 215), likely ruling out this energy-sparing mechanism. Physical activity levels are slightly lower in the initial 3 months of breastfeeding comparing with non-pregnant non-lactating women (212, 215), reflecting a relatively sedentary lifestyle. Fat storage from pregnancy tends to be at a minimum among poorly nourished women (206, 214), indicating limited ability to mobilize energy from fat. Consequently, much of the energy gap needs to be filled by dietary intake that is unlikely to be fulfilled in a food insecure environment. Milk energy density has been found to be positively correlated with maternal body fatness (216, 217). A low quality diet associated with household food insecurity unlikely provides sufficient bioavailable micronutrients in the diet. Responsive to dietary intake, maternal vitamin and mineral stores in pregnancy and vitamin content in milk (vitamin A, B6, B12, thiamin, riboflavin, etc) are at higher risk of deficiency (208, 218). Infant depletion in postnatal growth may continue as a result of low micronutrient intake from breast milk (219).

Altered feeding practice

Household food insecurity alters maternal-infant interaction (220) and feeding behavior (221), most likely through depression and changes in parenting (221, 222). Among low-income families with young children, recent findings have linked household food insecurity to a three-fold higher risk of maternal depression (124, 223). The prevalence of a high level of maternal common mental disorders, defined as having more than 7 out of 20 depressive symptoms, is consistently higher among women living in food-insecure households vs women living under food secure households in Bangladesh (65% vs 41%), Vietnam (50% vs 20%) and Ethipoia (46% vs 26%) (222). In one study, there was also a pattern of suboptimal infant and young child feeding practices among mothers with common mental disorders in the three countries, although the overall effect of household food insecurity on infant feeding practices was not tested in the study (222). In other studies, evidence was found that directly linked household food security status with altered breastfeeding (136, 224) and complementary feeding (136). Qualitative research among a group of Kenyan women discovered that moderate and severe household food insecurity was associated with perceived barriers of exclusive breastfeeding for the first six months, including beliefs in the insufficiency of breast milk alone for babies and adverse health or social problems for women who practice exclusive breastfeeding (224). In rural Bangladesh, duration of exclusive breast-feeding and duration of any breast-feeding was not different by household food security status; however, poorer feeding practices were found to be associated with food security—namely, the early introduction of juice, cow milk, other liquid and solid food (136). From the second half of infancy to 1 year of age, infants benefited from household food sufficiency and were more likely to be fed with semi-solid food, solid food and other nutritious foods (136). In one study, an infant feeding practice score was created against the WHO/UNICEF infant feeding recommendation, where higher scores indicated better feeding practices (136). The score for feeding practices during 6-9mo and 9-12mo, but not 3-6mo, was significantly higher in food secure households after controlling for maternal education and wealth index (136), indicating that an independent effect of food insecurity on infant feeding emerges when children eat more food from the family table.

Adverse child health outcomes

Household food insecurity may be a contributor to adverse child health outcomes. In a cross-sectional study of 26,339 rural households in Indonesia (225), food insecurity was independently related to a slight but significant increase in risk of neonatal (OR=1.05, 95%CI: 1.02-1.09), infant (OR=1.06, 95%CI: 1.03-1.09) and under-5 child mortality (OR=1.07, 95%CI: 1.04-1.10) after adjusting for maternal demographic (age), biological (BMI) and socio-economic factors (maternal education, household size, weekly per capita household expenditure). Among children less than 3 years old, household food insecurity was related to a 33% increased risk of hospitalization (226, 227) and poorer child health rating (227) in the

US. There are multiple hypothesized mechanisms: first, to cope with household food insufficiency, women may have less time for child care. For example, food-insecure women may have to do some paid jobs to make ends meet, which keeps mothers away from children, resulting in reduced time for child care, decreased child care quality (228) and increased risk of childhood undernutrition (229). In Sri Lanka, increased mother's income, although increasing total economic access to food, reduced the relative allocation of calories to children (230), indicating time constraints to properly feed the children while employed. Additionally, maternal depression may interfere with responsive care-giving (231), which likely puts the child at higher risk of illness, such as diarrhea and respiratory infections. Black et al (232) identified a partially mediating effect of caregiving practices observed at home in the relationship between maternal depressive symptomatology and infant growth at 6-12 month of age in rural Bangladesh (232).

Summary

In poor settings, women living under household food insecurity are likely eating a poor-quality low-calorie diet that puts them at higher risk of micronutrient and macronutrient deficiency. Poor nutritional status of these women is frequently observed. However, except for a few studies conducted in developed countries, maternal diet and nutrition during gestation and lactation in relation to household food insecurity has not been fully understood in poor settings. Impaired child growth is an adverse consequence resulting from both prenatal factors passed down through the nutritional pathway and postnatal factors, such as altered feeding practices and altered child care practices. The complexity of the underlying mechanism explaining the association between observed household food insecurity and infant growth faltering also remains largely unknown. Relationships between food insecurity status and maternal and child nutritional outcomes are often examined with one life stage as a focus. There are research gaps in exploring these relationships from a longitudinal perspective across critical life stages from pregnancy, through lactation to subsequent growth.

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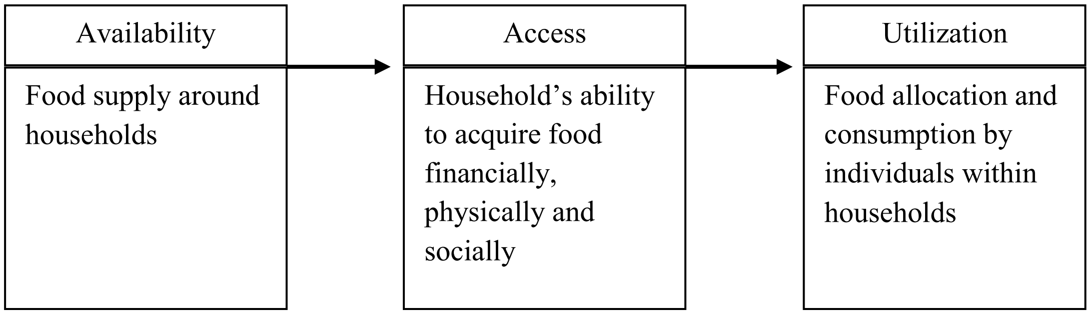
Figures and Tables for Chapter 2

Table 2.1: The evolution of the definition of food security

Year	Organization/Conference	Definition	Emprases
1974	World Food Summit (1)	The availability at all times of adequate world *food supplies* of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices	Food supplies: volume and stability
1983	FAO (2)	Ensuring that all people at all times have both physical and economic *access* to the basic food that they need	Included food access by vulnerable people
1986	World Bank (3)	Access of all people at all times to enough food for an *active, healthy life.*	Involved the health consequences of food security
1996	World Food Summit (4)	Food security, at the individual, household, national, regional and global levels when all people at all times, have physical and economic access to sufficient, *safe and nutritious* food to meet their dietary needs and *food preferences* for an active and health life.	Broadened to 1) food safety in addition nutrition adequacy; 2) involved food preferences
2001	The State of Food Insecurity (5)	food security is a situation that exists when all people, at all times, have physical, *social* and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life	Recognized the socially acceptability as a component

Summarized based on the description appeared on FAO 2003 (233)

Figure 2.1: The hierarchical nature of the food insecurity concept



Created from the concept described in Webb et al 2006 (6).

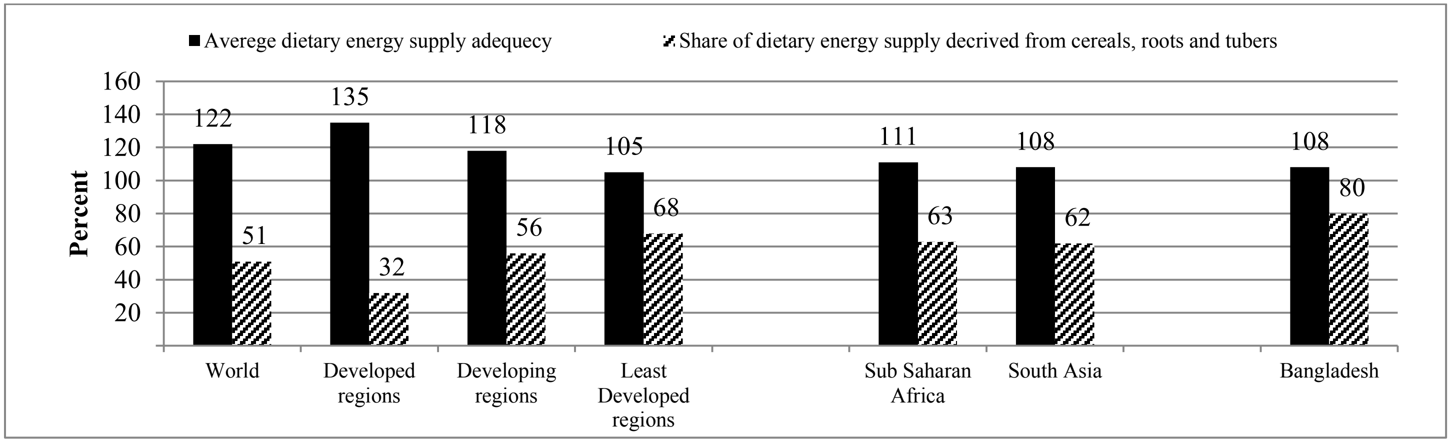
Table 2.2: Comparisons between household food insecurity (access) scales

	US-HFSSM (10)	**FAST** (15)	**MINIMat scale** (16)	**HFIAS** (17)
# of questions	10	9	11	9
Recall duration	1 year	1 year	30 days	30 days
Scale format	Nested/ Likert	Likert	Yes/No+ Likert)	Nested/Likert
Domain/Subdomain				
Uncertainty and worry	**X**	**X**		**X**
Inadequate quality	**X**	**X**	**X**	**X**
Not healthy or propoer	X			X
Limited variety			X	X
Less preferred	X	X	X	X
Insufficient quantity	**X**	**X**	**X**	**X**
Quantitiy of food not enough		X	X	
Eating less	X	X		X
Skipping meals	X	X	X	X
Running out of food	X	X		X
Socially unacceptable acquisition		**X**	**X**	
Resource augmentation strategies		X	X	
Other strategies			X	
Hunger and physical consequences	**X**			**X**

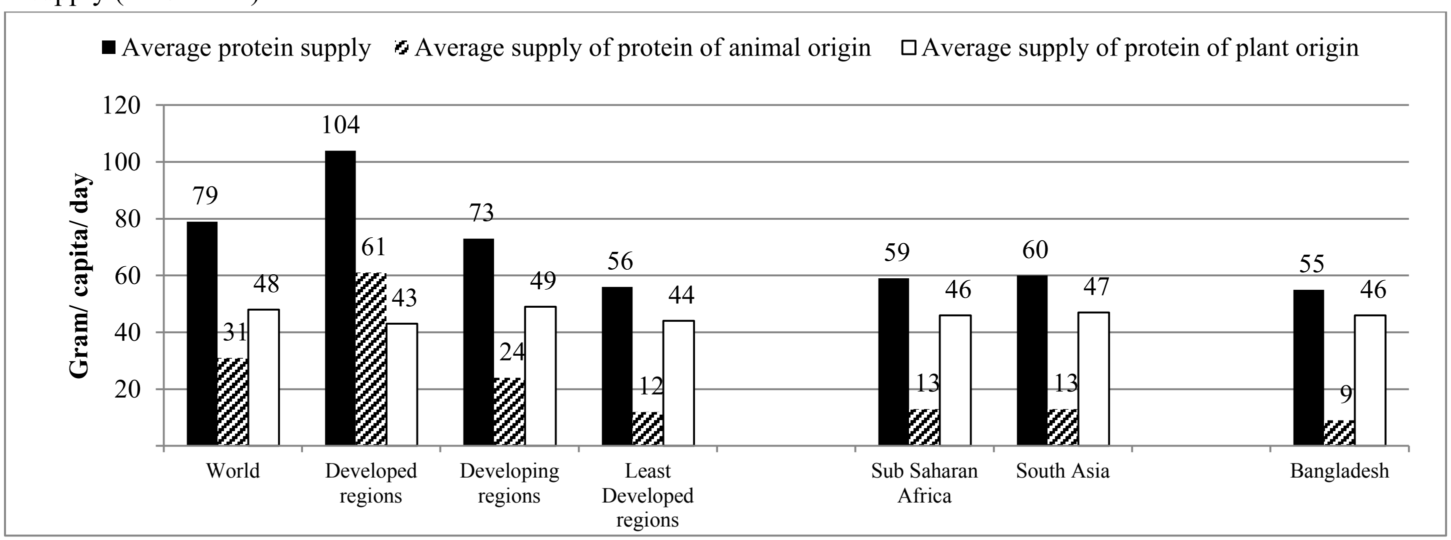
Adapted from Coates et al 2006 (19).

Figure 2.2: Food availability in different regions of the world

2.2A: Dietary energy supply (2011-2013)

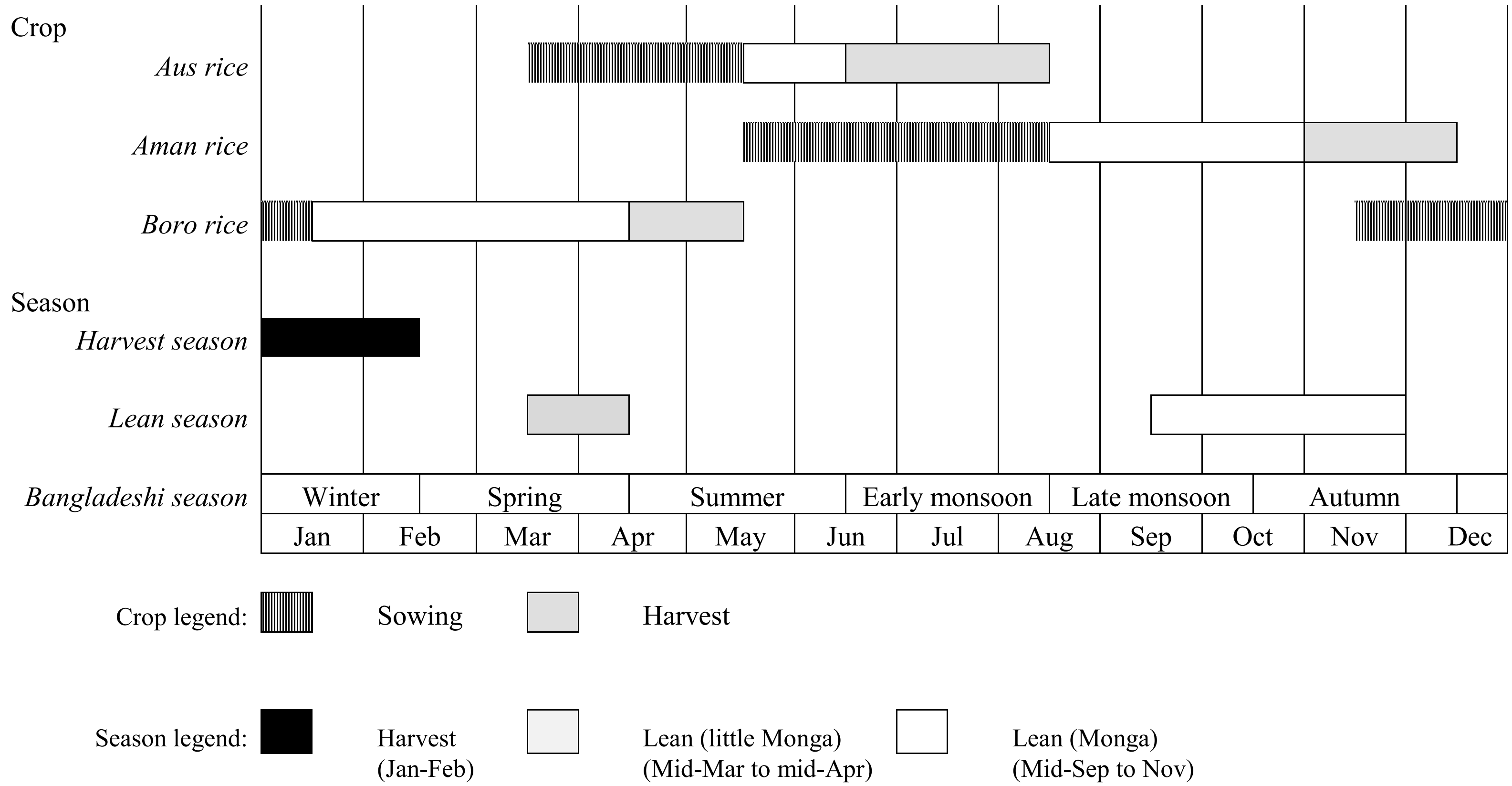


2.2B: Protein supply (2009-2010)



Data source: Food security indicators, FAO 2013. Plant-origin protein is calculated as the difference between total protein supply and animal-origin protein supply (24)

Figure 2.3: Crop calendar and season distribution in Bangladesh



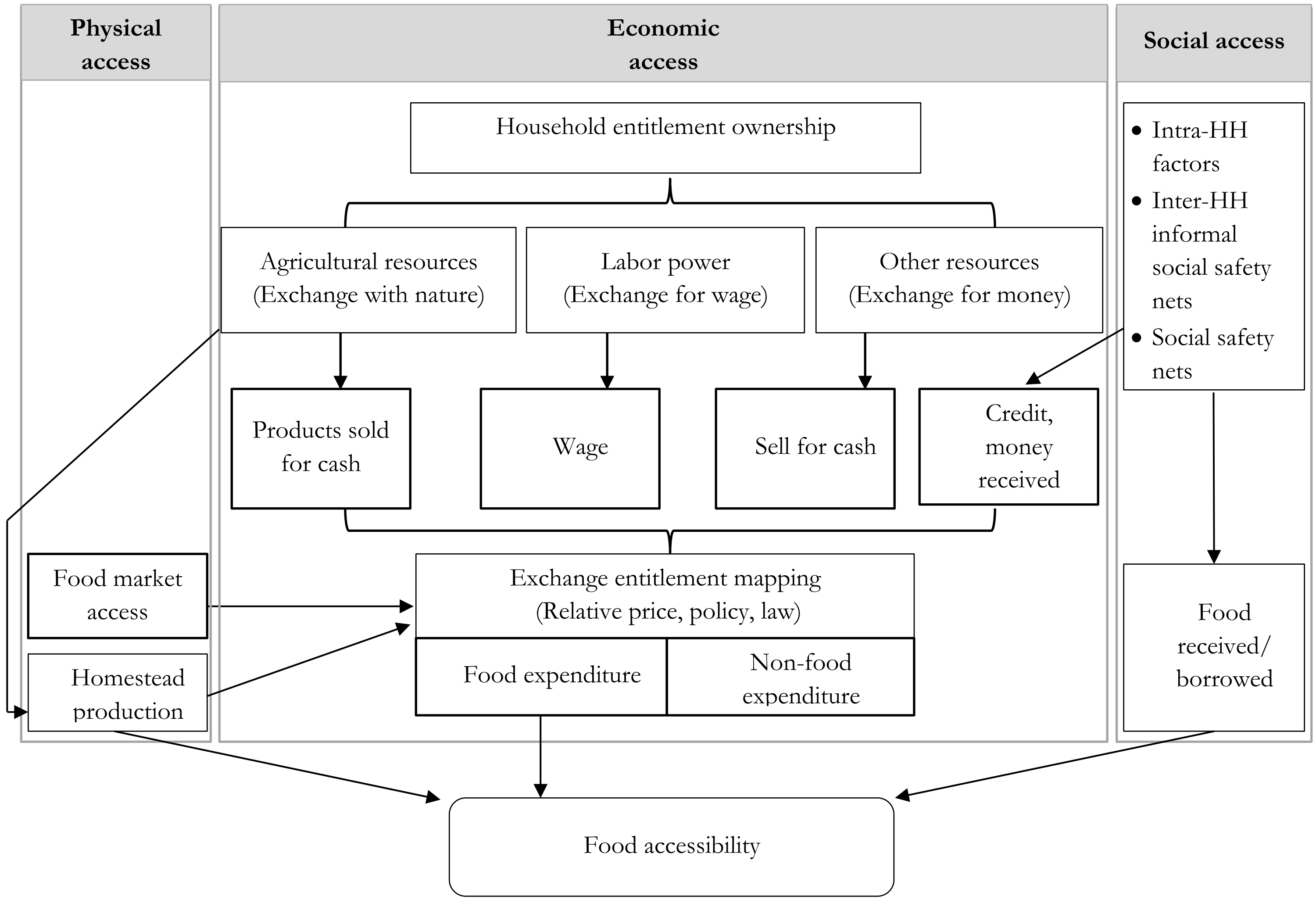
Adapted from (27)

Table 2.3: Example crops cultivated by agricultural season in Bangladesh

	Kharif (April-November)	Rabi (November-March)
Cereal	Aus rice, Aman rice, millet, sorghum	Boro rice, wheat, barley
Tuber and root crops	Panikachu, mukhikachu	Potato
Pulses	Black gram, mungbean, pigeon pea	Chickpea, lentil
Vegetables	Okra, red amaranths (DGLV), Indian spinach (DGLV), bitter gourd, pointed gourd, summer tomato	Cabbage, tomato, radish, spinach (DGLV), bottle gourd
Fruit	Banana, pineapple, papaya	Watermelon

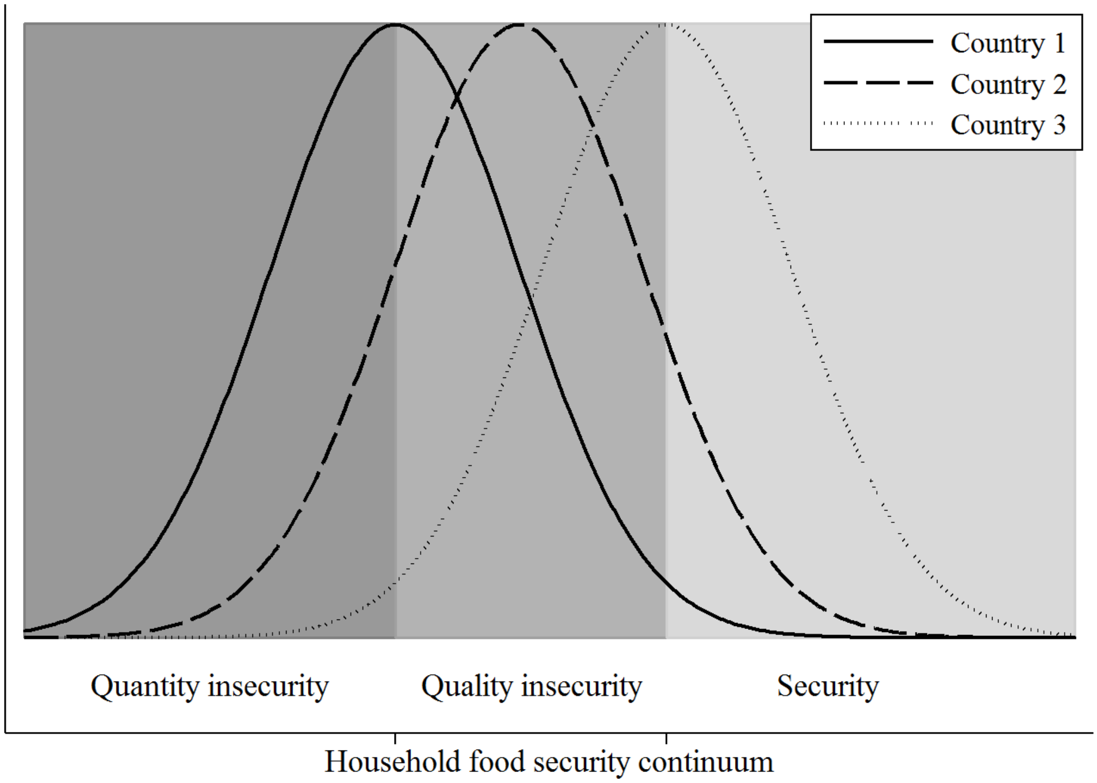
Summarized from description appeared on (27)

Figure 2.4: Conceptual framework of the relationship among predictors of household food accessibility in rural Bangladesh



Abbreviations: HH, household.

Figure 2.5: The conceptual distribution of household food insecurity reflected by the same scale in different settings



Note: Figure 2.3 is a conceptual illustration of hypothetical countries that have different household food insecurity problems: country 1 (solid line) has relative more severe food insecurity problems because half of the population is suffering from insufficient calorie intake due to food quantity insecurity; country 2 (dash line) have the medium severity of food insecurity; country 3 (dotted line) has the best food security among the three countries. Half of the population is actually food secure but nearly another half have food quality insecurity by eating less nutritious and healthy food.

CHAPTER 3: Methods and Materials

Overview

This dissertation focuses on exploring the influence of household food insecurity (HFI) and nutritional outcomes of mothers and infants from early pregnancy to first half of infancy. Extant data from the third JiVitA Micronutrient Research Project' study (referred as JiVitA-3 study) was utilized in this dissertation. JiVitA-3 is a cluster-randomized prenatal micronutrient supplementation trial, which enrolled more than 40,000 newly pregnant women aged 13-45 years between 2007 to 2011 in northwest rural Bangladesh. Partial data of 18,841 women enrolled between July 2008 to September 2011 was available for secondary analysis at the time of data request. At enrollment, a structured interview was administrated to collect information about baseline socioeconomic status (SES). In this prospective cohort, women were followed from early pregnancy to early lactation in which their dietary intakes and anthropometry were assessed. Infants of enrolled women were followed at birth and 6 mo of age and data on child breastfeeding and complementary feeding practice, anthropometry and morbidity were collected. HFI was assessed by the Food Access Survey Tool (FAST) at 6 month postpartum. The three aims of the dissertation are presented in **Figure 3.1**. For aim 1, multivariate linear regressions were used to link HFI and maternal dietary quality at 1st and 3rd trimester and 3rd month postpartum. Multivariate logistic regressions were used to further analyze the odds of consuming each individual food group comparing women from food insecure households with women from food secure households. For aim 2, multivariate linear regression models were used to study the trajectory of maternal weight and mid-upper arm circumference (MUAC) during pregnancy and during lactation by HFI status. For aim 3, mediation analyses was used in a set of multiple linear regression models to explain the observed association between HFI and infant size at 6 month with cumulative adjustment on maternal nutrition, birth size, postnatal factors and other contextual factors.

Before answering the core research questions of the dissertation, the validity of using a summative index from the 9 items of FAST was first established. The internal validity of the summative index was tested against the latent food insecurity score created under the item response theory (IRT), which is a parametric nonlinear factor-analytic approach modeling item-wise response patterns. The external validity of the HFI index was examined by studying the relationship between the index and predictors of physical and economic food access identified in the conceptual framework (**Chapter 2 Figure 2.2**). To further understand longitudinal HFI in our study population, data collection was conducted with a cross-sectional JiVitA Cohort Update Survey (JCUS) on selective SES variables and FAST items between February and March in 2012. The average interval between the FAST data collected at 6MP and at JCUS was 1.2 years. The dependability of FAST was examined by comparing the change in SES over the two assessments with the change in responses to selective FAST items.

This chapter introduces the methods and materials used in this dissertation, specifically the context of study area, the structure of data collection in JiVitA-3 trial and JCUS, definitions of study variables and statistical methods.

Study Context

The JiVitA-3 trial was undertaken in a contiguous area of approximately 435 square kilometers with a population of about 650,000 in the Gaibandha District, located in the northwest part of rural Bangladesh (1) (**Figure 3.2**). Though women's literacy and education level appeared higher in our study area, compared with Bangladesh rural statistics (2), our study population have poorer dwelling characteristics (electricity availability, wall material, and toilet facility) (**Table 3.1**). At baseline (2008-2011), the proportion of households reported ownership of livestock was higher in our study area than the proportion reported in the 2007 Demographic and Health Survey (DHS) in rural Bangladesh. Such differences diminished when compare data from the JCUS in 2012 against the 2011 DHS (3). The Bangladeshi DHS for the first time included five FAST items in the 2011 survey, providing an opportunity to directly compare food insecurity status with the national survey. We applied the same definition of food insecurity and calculated the prevalence of HFI using the same five items assessed in DHS 2011: 52.3% of households were food insecure in our study area in the period of 2008-2011 vs 38.9% of the rural sample in the national survey in 2011. Consistent with reported HFI, the proportion of undernourished women, defined as BMI<18.5kg/m^2, was greater by 7% in our study area (40%) than the national rural sample (33%). The prevalence of low birth weight (LBW) was about 36% in the JiVitA-3 trial. The LBW rate is higher in JiVitA-3 than the national rate, which is also observed in a previous JiVitA trial (4).

To summarize, our study area represents an average to below-average socioeconomic status context. The food insecurity, maternal malnutrition and low birth weight are more prevalent among our study population than national sample. The generalizability of the results from this dissertation is likely to exhibit true association between food insecurity and nutritional outcomes among the rural poor.

Data Collection

JiVitA-3 trial

JiVitA-3 was a two-arm cluster-randomized trial designed to examine the efficacy of daily antenatal supplement of multiple micronutrients versus folic acid and iron use alone on maternal and child nutrition and health outcomes. Married women of reproductive age (13-45 years) were placed under a prospective pregnancy surveillance, during which they were visited at home every 5 weeks and were asked about having menstruated in the previous month. Amenorrheic women were offered a chorionic gonadotropin test in urine test to confirm pregnancy. Newly identified pregnant women were then consented to be enrolled into the trial and begun to receive study supplements on a weekly basis through 12 weeks post-partum. At enrollment, participating women were visited at home, usually during their first trimester of pregnancy (1TM), to collect information about previous pregnancy history, frequency of dietary intake, anthropometry, household composition and household SES. Women were then followed during their third trimester (3TM), 1 month (1MP) and 3 month postpartum (3MP), when their dietary intake and anthropometry were assessed according to structured questionnaires. At 3MP, women were also asked about their breastfeeding practices in the previous day.

A community-based birth notification system was set up to permit quick identification of participating women who have just give birth. Usually within a week, trained female interviewers would visit women's homes to assess birth anthropometry. At 6 month postpartum (6MP), infants were followed again to collect data on anthropometry, feeding practices and morbidity in the past week. The FAST module was implanted in the structured questionnaire at 6MP. **Table 3.2** presented extant data being analyzed in this dissertation from the JiVitA-3 cohort.

JiVitA Cohort Update Survey (JCUS)

To update vital and residential records and basic health, nutritional and socioeconomic profiles, we have developed a module (referred as JiVitA Cohort Update Form, or JCUF; see **Appendix 1**) for all women and their live offspring who have ever enrolled in the JiVitA-1, the first clustered-randomize controlled trial comparing weekly vitamin A or beta carotene versus placebo antenatal supplementation on maternal, fetal and infant mortality, and JiVitA-3 trial. Approximately 165,000 women and 70,000 children across both trials were visited by 300 trained female staffs and 99.9% of the sample was surveyed from February 2012 to March 2012.

Women's geographical and demographic identifiers, were preprinted on the form for interviewers' to confirm with the interviewee's information. Once the identifiers were matched, staffs proceeded to request consent of continuing the JCUS with women or other household members in case of maternal death or other reasons for not met. Consented women or other family members would continue the survey and would be asked for household information, including household size, number of assets owned (almirahs, clocks, cots/beds, living and sleeping rooms, mobile phones), construction of ground floor walls, electricity availability, types of vegetable and fruits grown, number of livestock owned (chickens/ducks, goats/sheep, cows/buffalos), ownership over fishpond, and the perceived content of iron in the drinking tubewell.

Two items from FAST, frequency of rice procurement and frequency of worrying about food in the past 6 months, were selected due to their high sensitivity in detecting milder food insecurity from preliminary analysis (5). Three other food insecurity questions were adapted from the Household Hunger Scale (HHS), which intended to screen severe HFI (6). There were three items on HHS and respondents were asked to recall the frequency in the past 30 days of a) no resources for food; b) sleeping at night hungry; and c) whole day and night without eating. Data from JCUS is used to test external validity and dependability of the FAST scale.

Definition of Study Variables

The three aims of this dissertation involve analysis of extant data from JiVitA-3 trial. As shown in Table 3.2, socio-economic status, diet and anthropometry data were collected throughout the follow up and variables of analytic interest are formed. The definitions of independent and dependent variables used in this dissertation are described below.

Independent Variables

Household Characteristics

Household size and Dependency ratio

At enrollment women were asked the number of preschoolers (<5 y), school-age children (5-12 y), adolescents (13-18y), adults (18-50y) and elderly (≥50y) live in the family. Baseline household size was calculated as the total number of people of all age groups. Dependency ratio was calculated as the total number of people aged 0-12 and aged over 50 years living in the family divided by the total number of people aged 13-49 years. At JCUS round, household size was directly assessed by asking the respondent how many members were there living in the household.

Wealth index (WI)

A structured questionnaire was applied to collect information on a) dwelling characteristics, such as number of living rooms, type of toilet facility, and electricity availability; b) ownership of durable assets; and c) ownership of agricultural resources including land and livestock. Household construction of the ground floor, roof and kitchen was assessed by the interviewer based on direct observation. A wealth index using selective socioeconomic variables was created according to a previous published methodology (7). The wealth index was cut into tertiles for descriptive purpose and was adjusted in regression analysis as a continuous variable.

HFI index (HFII) and HFI categorization

At 6 mo postpartum (6MP), women were asked to respond to the FAST, a Likert scale, by recalling the frequency of their food insecurity experiences in the past 6 months, including concerns and anxiety over food acquisition, reduction in food quality and/or food quantity, and socially acceptable strategies used to cope with HFI, such us taking out loan from shops, and borrowing money to buy food. Question about "square meals" was reversely coded because it is the only question about sufficiency instead of deprivation. The sum of the 9 frequency responses was used as a HFI index (HFII) with higher score representing severe food insecurity status. Households with zero value HFII were classified as food secure and the rest of the households were categorized into mild, moderate and severe groups on the tertile cutoffs of all non-zero HFIIs.

Maternal Characteristics

a) Demographic factors

<u>Age</u>

Maternal age in the week of positive urine chorionic gonadotropin test was recorded during the pregnancy surveillance. Maternal age was explored and adjusted as a continuous variable.

<u>Religion</u>

Women's religion was reported during the baseline SES assessment at enrollment. Because our study area is a Muslim-dominant community, the distribution of religion was explored by two broad categories: Muslim and non-Muslim religion.

<u>Education</u>

Upon enrollment, women were asked about their highest class they have completed in school. If no schooling was the answer, women were considered as having no education. If women had any education done, including primary education (class 1-9), secondary education (class 10-12) and higher education, they were categorized into the primary or higher education group.

<u>Employment</u>

Aside from women's house chore, women were asked if they were working at the time of enrollment for which they were paid in cash or in kind. Those reported affirmative answer were considered having a paid job and those who gave negative answers were considered as not employed.

b) Pregnancy history

<u>Parity</u>

Women's lifetime pregnancy history was asked as part of the structured interview at enrollment. Parity was counted as the total number of previous live births. Based on parity, women were categorized into primiparous women (parity=0) or multiparous women (parity=1, 2 or more).

<u>Proceeding pregnancy outcome</u>

For multiparous women, their proceeding pregnancy outcome prior to the current pregnancy was recorded as one of the following categories: live birth, stillbirth, miscarriage, or induced abortion/ menstrual regulation. Proceeding pregnancy outcome was further dichotomized into live birth or other (stillbirth, miscarriage and induced abortion/ menstrual regulation).

<u>Proceeding interpregnancy interval</u>

If a woman previously had one or more pregnancies, the woman was asked to recall the month and year of the outcome of each pregnancy she had experienced. The proceeding interpregnancy interval was calculated as the difference between the LMP date of the current pregnancy and the outcome date of the most recent pregnancy. A dichotomous group was created to distinguish multiparous women who had a proceeding interpregnancy interval equal or longer than 18 mo versus women who had an interval less than 18 mo.

c) Behavioral factors

Heavy physical activity

Selective heavy physical activities were asked to women based on the rural Bangladeshi culture, including 1) carried heavy objects (≥20 kg); 2) husked, ground or pounded grain; 3) gathered and/or cut folder; 4) chopped or cut fire wood, and 5) walked more than one hour. Each woman was labeled as any versus none of the work done at 3TM and at 3MP.

Breastfeeding behaviors

Whether or not woman was still breastfeeding their baby was assessed at 3MP and 6MP. The intensity of breastfeeding was also assessed by asking the women about feeding frequency during the past day and whether the infant get sufficient breast milk as it wanted. Women were asked to recall the times of breastfeeding in the day prior to the interview day and the trained interviewer will record the answer into one of the breakdown category: 1-10 times, 11-20 times or more than 21 times.

Complementary feeding behaviors

At 6MP, introduction of non-breast milk foods in the previous 7 days was asked. Added items were grouped into 11 food groups according to WHO Infant and Young Child

Feeding Module (8): 1) Infant formula; 2) milk (fresh or powdered); 3) dairy (yogurt or other dairy); 4) plain water; 5) any grains (suji/payesh, wheat/rice flour gruel, tapioca, rice, Khichari); 6) dal; 7) banana; 8) biscuit; 9) added oil (oil or ghee); 10) added sugar and 11) other food. Ten dichotomous indices of whether the infant was fed with each food group were created.

Infant Characteristics

Age

Infant age at the 6 month follow up was calculated as the difference between the interview date and the birth date recorded from the community-based birth notification system. For exploration purpose, infant age was grouped into <6 mo, 6-7 mo and ≥8 mo. Infant age was adjusted as a continuous variable.

Preterm birth

Gestational age (GA) in weeks at birth was calculated based on the interval between the dates of LMP and delivery. Preterm birth was defined as less than 37 weeks of gestational age before delivery.

Morbidity

At 6 months postpartum, history of morbidity symptoms in the prior week was assessed including acute respiratory disease, diarrhea, dysentery and fever. Women were asked about the number of days that her child has had each symptom in the previous 7 days and the number of zero to seven was filled upon women's response. A dichotomous variable of whether the infant developed each symptom in the past week was created for exploration and adjustment purpose.

Other Controlled Variables

Seasonality

At each maternal diet follow up at 1TM, 3TM and 1PM, six standard seasons were defined based on dates of food frequency questionnaire (FFQ) assessment using the Bangladeshi calendar: winter (mid-December to mid-February), spring (mid-February to mid-April), summer (mid-April to mid-June), early Monsoon (mid-June to mid-August), late Monsoon (mid-August to mid-October) and autumn (mid-October to mid-December) (9). Six seasons were also created based on the HFI assessment date using the same definition.

Time intervals between assessments

Women's last menstrual period (LMP) was obtained from the 5-week pregnancy surveillance visits. GA in weeks at each visit was calculated as the interval between the date of LMP and date of 1TM or 3TM visit during pregnancy.

Postpartum weeks at 1MP or 3MP visit were calculated as the interval between the date of interview and the date of birth. The GA length from 1TM to 3TM and duration between two postpartum assessments were calculated as the interval between two consecutive visits during pregnancy and during lactation, respectively.

Dependent Variables

Aim 1

Women's dietary diversity scores (WDDSs)

In the 1TM and 3TM in pregnancy and 3MP in lactation, women's usual diet by a 7-day FFQ was assessed. Frequency of consumption of 32 food items during the past 7 days was asked to participating women. The 32 food items or food groups were then grouped into 11 food groups according to the FAO recommendations (6), namely non-rice starchy staples (wheat and potato), dark green leafy vegetables (DGLV), vitamin-A rich fruit and vegetables (VAFV, pumpkin, mango, papaya), other fruit and vegetables (taro stem, pointed gourd, bottle gourd, radish, cabbage, bitter gourd, eggplant, okra, tomato, beans, banana, jackfruit, guava), legumes and nuts (peanut, pulses and food made with pulses), organ meat (any kind of liver), meat (goat, lamp, beef, chicken, duck, goose), fish (fresh fish, dried fish, prawn), eggs (any poultry eggs), dairy (milk or curd) and vegetable oil. A dichotomous consumption variable of whether the woman had consumed any item within each food group was created. Women's dietary diversity score (WDDS) was calculated as the sum of the number of the dichotomous consumption variable for each food group excluding oil, ranging from 0 (no food group in the past 7 days) to 10 (maximum diversity).

Aim 2

Maternal anthropometry

Women's height was measured twice at 1TM and 3MP using a portable stadiometer to the nearest 0.1 cm. Women's weight and mid-upper arm circumference (MUAC) were measured twice during pregnancy in 1TM and 3TM and twice during lactation in 1MP and 3MP. Women were weighted in light cloth on SECA digital scales (UNICEF) to the nearest 100 g and their MUAC was taken using an insertion tape to the nearest 0.1 cm. Triplicate measurements of height and MUAC were taken at every assessment and the median of the three was used as the representative value. Maternal body mass index (BMI) was calculated as weight/ height^2 (kg/m^2) and low BMI was defined as a BMI value less than 18.5 kg/m^2.

<u>Absolute change in nutritional status</u>

For each woman, their weight and MUAC were measured twice in pregnancy and twice during lactation. Maternal gestational weight gain from 1TM to 3TM was calculated as the weight measured in 3TM minus the weight measured in 1TM. Maternal weight lost in lactation was the weight measured in 3MP minus the weight measured in 1MP. The absolute changes in MUAC from 1TM to 3TM in pregnancy and from 1MP to 3MP in lactation were calculated for each woman using the same algorithm.

Aim 3

<u>Infant sizes at 6 mo</u>

A community-based birth notification system was set up to enable trained field staff to visit mothers and newborn children usually within a week after birth to assess infant size. Naked birth weight of infants was measured to the nearest 10 g on a TANITA BD-585 scale (Tanita Corporation, Arlington Heights, IL); recumbent length was measured using a portable, plexiglass, folding length board with fixed head piece and sliding foot block modified from the Infant Shorr board and head, chest and left mid-upper arm circumference measurements were taken using an Ross insertion tape (Abbott Laboratories), all to the nearest 0.1 cm, following previously described methods (10). The median of triplicate measurements was taken as the representative value.

Risk of infant malnutrition at 6 mo

Infant weight and length measurements were converted to weight-for-length (WLZ), weight-for-age (WAZ), and length-for-age (LAZ) z-scores using the World Health Organization (WHO) Multicenter Growth Reference Study child growth standards, using WHO Anthro Version 3.2.2 (WHO, Geneva, Switzerland). Wasting, stunting and underweight were defined as <-2 z-score for WLZ, LAZ and WAZ, respectively.

Statistical Analysis

Validity of using a summative HFI index (biostatistics paper)

The internal validity of the sum of polytomous responses of the FAST scale, or the HFI index (HFII), was examined by comparing the HFII with the food insecurity latent score estimated from graded response models (GRMs) under the item response theory (IRT). First, four core assumptions of IRT, unidimensionality, monotonicity, local independence and measurement invariance, were checked by examining the correlation among the 9 items of FAST and correlation between item responses and key characteristics of respondents (race, education, etc). Second, GRMs were fit with adjustment of item pair-wise dependences that were identified in the previous step. Likelihood ratio tests were performed to identify the most efficient GRM, which was used to estimate the food insecurity latent score. Comparison between the latent score and HFII was executed in the form of continuous variables using scatter plot and linear regression. To examine the agreement of the two methods in categorizing households into four groups (food secure, mild, moderate and severe HFI), the raw percentage of agreement and Kappa statistics were calculated.

The external validity of HFII was explored by modeling the relationship between the index and predictors of physical and economic food access. The mean value of the index and the odds of HFI, defined as non-zero HFII were compared by whether or not the household owned agricultural resources and by whether or not the household involved in income-generating activities. Comparisons of mean HFII and odds of HFI were also performed by other SES variables, including household size, ownership of durable assets, construction of wall and wealth index, a summary index for the overall household SES status.

Another piece of analysis was executed to examine the dependability of FAST. Households were classified into three groups based on the dynamic change in the responses to FAST items over the two assessments at 6MP and at JCUS: those who had improved household food security, those who had unchanged food security status, and those who had worsened household food security. Using SES data collected at enrollment and at JCUS, change in household size, house construction, and proportion of ownership over durable assets were calculated and were compared across the three HFI dynamic groups.

Aim 1: HFI and maternal dietary quality (paper 1)

All of results were reported by HFI index category, where HFI is treated as a categorical variable. The one-way analysis of variance, or ANOVA test, was used to test equal means of WDDSs across categorical HFI groups at three assessments. Chi-square tests were used to examine the relationship between HFI groups and whether or not women consumed each food group. Pair-wise T-test was used to examine whether WDDSs consumed by the same women changed over longitudinal assessments. Logistic regression analyses were used to estimate the odds of consuming each food group by comparing women from food-insecure households with women living with food security (reference). The bivariate logistic regression only included HFI groups and binary outcome of whether or not a food group was consumed. In the multivariate logistic models, we further included maternal and socioeconomic variables that are significantly associated with both HFI and WDDSs. P-values less than 0.05 was considered as significant. Because of multiple comparison among likely correlated outcomes, we also applied a Bonferroni correction with cutoff at 0.001, which is 0.05 divided by 33 the total number of food group outcomes examined (11 food groups times 3 assessments).

Supplementary data analysis was done to support result discussion. The difference in the proportion of any food group consumption was calculated comparing postnatal period and prenatal period (**Appendix 5.1**). For women who have reported any food group consumption, the consumption frequency for each food group was compared by HFI groups using non-parametric tests due to the skewness in the distribution (**Appendix 5.2**). Median frequency of consumption was plotted for each food group by season and by HFI status to explore the year-round variation in food consumption (**Appendix 5.3**). For the discussion of external generalizability, characteristics of included and excluded households were compared using ANOVA test for continuous variables or using Chi-square test for categorical variables (**Appendix 5.4**).

Data in paper 1 were analyzed using STATA/SE 13.1 (StataCorp, College Station, Texas).

Aim 2: HFI and maternal nutritional status (paper 2)

Multivariate linear regression methods were applied to model the absolute changes in weight and MUAC during pregnancy and during lactation in unadjusted models (model 1), adjusting for maternal factors only (model 2), and adjusting both maternal and household factors (model 3). In pregnancy, age, parity, BMI at enrollment, GA length, and physical work activities were recognized as maternal factors related to nutritional status change; at lactation, duration between postpartum assessments instead of GA length and additionally GA weight gain, breastfeeding frequency and sufficiency were included as first level adjustment for primiparous women. Two additional variables of proceeding pregnancy outcome and interval are included for multiparous women. Predictors for household food availability and allocation included seasonality, religion, household size, maternal education and wealth index. In the multivariate linear regression modeling approaches, food secure group was treated as reference group to be compared with women of food insecure households. The significance level of p-value was set at 0.05.

Multilevel models with random intercept, random slope and unstructured correlation were applied to examine the source of variances in maternal nutritional status and to see if there is any evidence supporting differentiated rate in the change of weight or MUAC by HFI status (**Appendix 6.1**). Categorical HFI was fitted in the multilevel models as dummy variables and in the interaction term with time. The multilevel models were formed in weeks of gestation or lactation as the following:

$$y_{ij} = \beta_{0ij} + \beta_{1ij} * Time_{wk} + \beta_{2g} * HFI_g + \beta_{3g} * HFI_g * Time_{wk}$$

$$\beta_{0ij} = \beta_0 + b_{i0}, \qquad b_{i0} \sim N(0, \tau_0^2)$$

$$\beta_{1ij} = \beta_1 + b_{i1}, \qquad b_{i1} \sim N(0, \tau_1^2)$$

$$Cov(b_{i0}, b_{i1}) = \tau_{01}^2$$

where y_{ij} is the weight or MUAC in pregnancy or lactation for individual i at assessment j (j=1 or 2); intercept term β_{0ij} is centered at the mean visiting week of the first assessment, representing individual nutritional status at the entrance of prenatal or postnatal assessments; linear term β_{1ij} is the change in weight or MUAC change per week; β_{2g} is the mean difference in nutritional status at entrance of assessments between each HFI group with food secure reference group. g=1, 2, 3 represents mild, moderate or severe HFI groups; interaction term β_{3g} is the difference in change rate in HFI groups comparing with reference group. The randomness τ_0^2 and τ_1^2 captured between-subject variation in initial status and in change pattern over time. Based on the estimation of variance structure from the model output, the percent of total variance observed that was attributable to the variance found in initial nutritional status was calculated.

To illustrate points raised in the discussion section, additional figures were plotted, including a) gestational weight/MUAC change from 1TM to 3TM by seaons and by HFI status (**Appendix 6.2**); b) birth weight by season and by HFI status (**Appendix 6.3**); c) postpartum weight and MUAC change by season and by HFI status (**Appendix 6.4**); and d) Hypothesized static ranking of chronic HFI over the year (**Appendix 6.5**).

Similarly, comparison was done between included and excluded households were compared in the maternal characteristics, infant characteristics and SES variables for the discussion of external generalizability of the research findings (**Appendix 6.6**).

All analyses for paper 2 were performed on STATA/SE 13.1 (StataCorp, College Station, Texas).

Aim 3: HFI and infant growth at 6 month of age (paper 3)

Nonparametric tests for linear trend across the ordered HFI groups were applied on maternal and infants' anthropometric measures. To study the pathway of HFI on early infant growth, we developed a conceptual framework, hypothesizing a maternal-pregnancy-nutrition pathway likely mediated by alteration in feeding practices and infant morbidity. A set of multiple linear regression models were applied with cumulative adjustment on a temporal sequence starting from nutritional status of mothers at early pregnancy, followed by birth size as a proxy for fetal growth outcome, and then the postnatal influences via diet, morbidity, socio-economic status (SES) and seasonality. Similarly, a set of multiple logistic regression models were used with the same adjustment procedure to study HFI and risk of wasting, stunting and underweight at 6 mo of age. Specifically, maternal height, MUAC and WDDS were used as indicators for maternal nutritional status and GA-adjusted birth length and the length-adjusted birth weight, ponderal index (PI), were used as birth size proxies. Feeding practices and child morbidity that were found significantly different with HFI status were included in the multiple regression models. SES variables included in adjustments were maternal employment, maternal education, and wealth index (WI). Other important factors that were associated with prenatal and postnatal growth were adjusted in the regression analysis prior to the introduction of the temporal sequence adjustment. These factors include maternal parity, age and GA at maternal anthropometric assessment, and infant sex and month age at 6 mo follow up. Percentage of reduction in coefficient with cumulative adjustments was calculated comparing with the coefficients from the unadjusted models.

The value of variance inflation factor (VIF) was estimated in the final model to examine potential collinearity issues (**Appendix 7.1**).

A couple of sensitivity analyses were performed on infant weight and length to explore the robustness of research findings. To address concerns on variable selections on the nutritional pathway, two sets of sensitivity analysis was conducted in the sequence of model fitting: a) adjustment for maternal BMI at 1TM instead of maternal MUAC (**Appendix 7.2**); and b) adjustment for birth weight instead of ponderal index (**Appendix 7.3**). There was no substantial difference in the coefficient estimates comparing the research findings with sensitivity analysis. We chose to present the current data in paper 2 given smaller VIFs compared with VIFs in the above sensitivity analyses.

The other two sensitivity analyses were performed to address the concern of the order of adjustment in the cumulative regression analysis. First, after the adjustment of fixed variables of infant sex, age and maternal parity, age and GA, a reverse order of adjustment was applied starting from postnatal factors and followed by birth size and maternal nutritional status (**Appendix 7.4**). If results were not sensitive to the order of adjustment, switching the order should not change the relative reduction in effect size. The other sensitivity analysis was performed with adjustment on SES factors first and followed by fixed factors and factors along the nutritional pathway (**Appendix 7.5**). Results of sensitivity analysis were discussed in Chapter 7.

For paper 3, analyses were performed using R 2.13.2 (The R Foundation for Statistical Computing). We set the primary level of statistical significance at $p<0.05$.

Ethical Considerations

The JiVitA-3 study was approved by the Bangladesh Medical Research Council, Dhaka (Reference BMRC/ERC/2007-2010/935), and the Institutional Review Board of the

Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland (IRB 00000570). The JCUS was approved as an amendment of the parent trial by Bangladesh Medical Research Council in December 2011 (**Appendix 2**) and by the Johns Hopkins School of Public Health Institutional Review Board in January 2012 (**Appendix 3**). Only registered study investigators have access to data (**Appendix 4**).

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Figures and Tables for Chapter 3

Figure 3.1: Structure of this dissertation

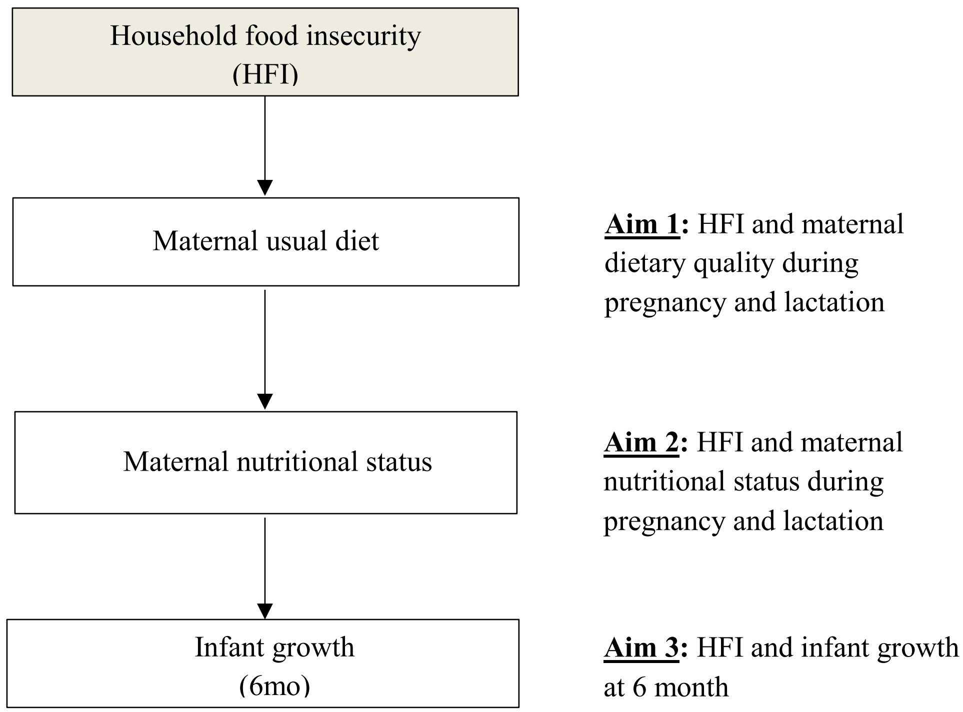

Figure 3.2: The research site of JiVitA Micronutrient Research Projects

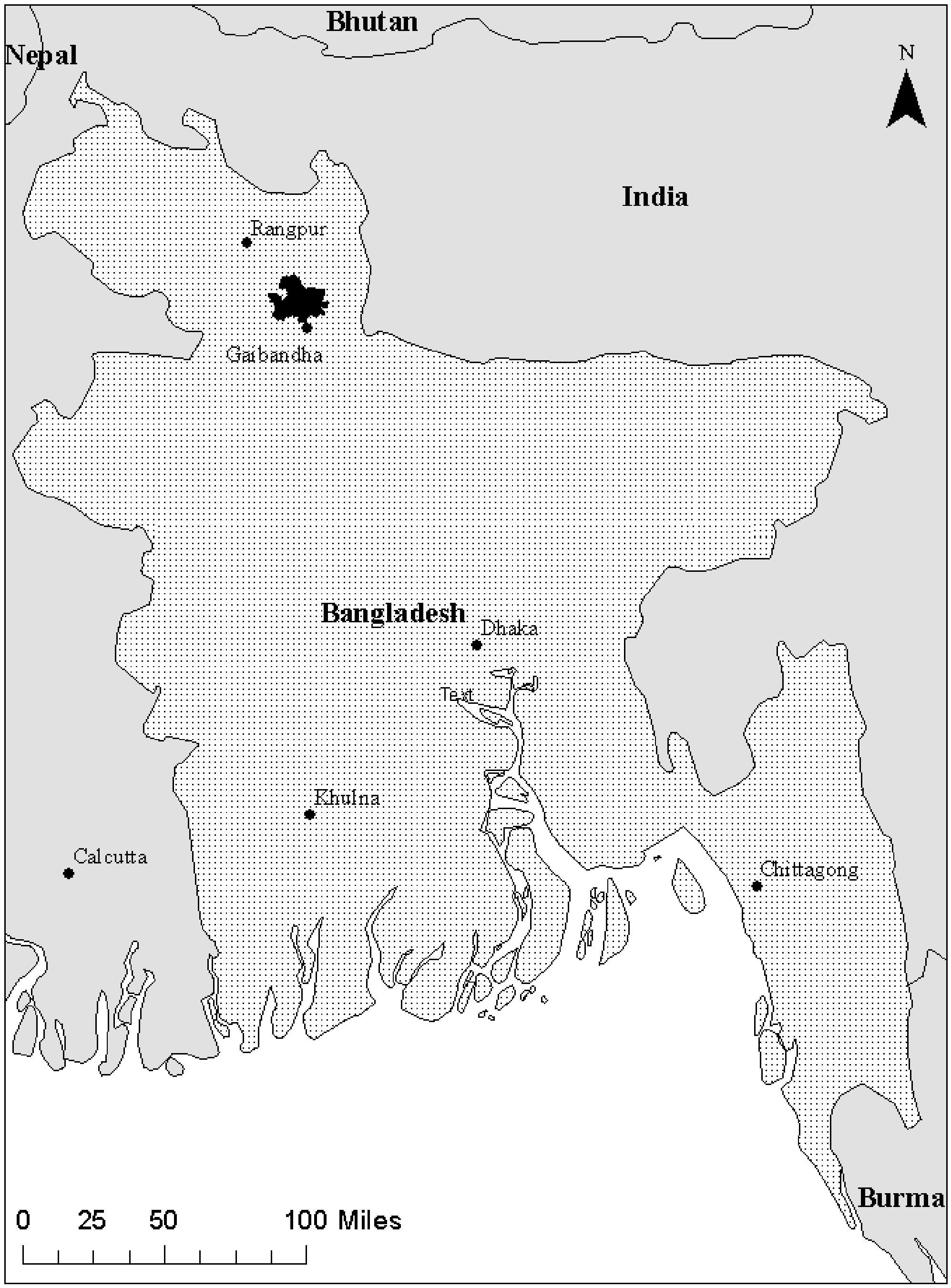

Table 3.1: Socioeconomic status and nutrition indicators for study area, rural Bangladesh and National estimates from 2008-2012

Indicator	Study Area		Bangladesh, Rural[a]		Bangladesh, National[b]	
Year	2008-2011	2012	2007	2011	2007	2011
Socioeconomic status						
Literacy rate among females	61.0	-	51.5	59.7	54.5	62.9
Proportion of women with any education	72.8	-	67.8	68.3	69.8	70.7
Mean household size	4.3	4.6	4.7	4.7	4.7	4.6
Electricity	22.4	28.5	36.6	49.3	46.5	59.6
Main wall material						
Poor material (Cane/palm/trunks, dirt, bamboo with mud)	26.0	15.9	45.5	-	40.0	-
Tin	64.7[c]	72.5[c]	40.7	-	37.5	-
Cement and bricks	9.3	11.5	12.4	-	21.2	-
Toilet facility						
No facility/bush field	26.6	-	10.2	5.8	8.4	4.6
Flush toilet	0.1	-	8.9	11.7	13.5	16.0
Livestock ownership						
Cows, bulls, buffalo	50.1	52.9	14.0	46.2	12.1	37.6
Goats, sheep	22.2	22.5	10.2	28.9	8.6	23.6
Chicken, ducks	75.5	62.1	6.7	70.3	6.0	58.9
Nutritional indicators						
Food insecurity	52.3	-	-	38.9	-	35.1
Had no square meals a day	18.2	-	-	21.0	-	18.7
Had skipping meals	11.4	-	-	20.3	-	18.1
Had less food in a meal	23.3	-	-	24.4	-	21.7
Bought rice frequently	42.8	52.6	-	19.3	-	17.2
Had to ask for food	21.1	-	-	36.5	-	32.8
Maternal undernutrition (BMI<18.5 kg/m^2)	39.7	-	32.6	28	29.7	24.2
Low birth weight	35.8	-	-	-	21.6[e]	-

a. DHS Bangladesh 2007 (2)

b. DHS Bangladesh 2011 (11)

c. Proportion represents both tin and wood plank

d. Food insecurity is defined as non-zero summative score of the five items.

e. UNICEF. Monitoring the Situation of Children and Women (12).

Table 3.2: Socio-economic status, diet and anthropometry data collected at household, maternal and infant level during each visit

		Prenatal period		Postnatal period			
		1TM	3TM	Birth	1MP	3MP	6MP
Household							
	SES	X					
	FAST						X
Mother							
	7-d FFQ	X	X			X	
	Height	X				X	
	Weight	X	X		X	X	
	MUAC	X	X		X	X	
Infant							
	Breastfeeding practice					X	X
	Complementary feeding practice						X
	Anthropometry[a]			X			X
	Morbidity						X

Abbreviations: 1TM, 1st trimester; 3TM, 3rd trimester; 1MP, 1 mo postpartum; 3MP, 3 mo postpartum; 6MP, 6 mo postpartum; SES, Socio-economic status; FAST, Food Access Survey Tool; FFQ, Food frequency questionnaire; MUAC, Mid-upper arm circumference;

a. Anthropometry measured were weight, length, MUAC, head circumference and chest circumference.

CHAPTER 4: Introduction of the Food Access Survey Tool (FAST)

Overview

The Food Access Survey Tool (FAST) was developed by Food and Nutrition Technical Assistance Project (FANTA) and was validated to measure food (access) insecurity in Bangladesh (1). It reflected the concept of food security in four domains: anxiety over food acquisition, quality of food, quantity of food, and social acceptability. Subjects were asked to recall the frequency of the following behavior or concerns in the past 6 month: eating square meals, eating wheat (instead of rice), skipping meals, eating less food, having no money to buy food, worrying about food, buying rice, taking out a loan from shops or borrowing money to buy food. Responses were provided on a Likert scale: 0=never (0 time/ 6mo);1=rarely (1-3 times /6 mo); 2=sometimes (4-6 times /6 mo); 3=often (a few times each week) or 4=mostly (most days per week). The JiVitA-3 study, with its longitudinal design and multiple assessments on dietary intake, nutritional status, health and socioeconomic measures, provided a unique opportunity to study household food insecurity (HFI), as assessed by the FAST scale, and nutritional outcomes from early pregnancy to postnatal period.

Examining the validity of behavior-based food access scales requires several special considerations (See Chapter 2). The criterion of *well-grounded construction* defines the overall construct validity. The *performance consistent with understanding* and *precision* indicate the internal construct validity. The first three criteria, referring to the internal validity of the scale, are rooted in the development stage of a scale (1) and the implementation stage of the FAST (2). *Dependability*, on the other hand, expects a given scale capture the longitudinal latent variable over time. The *accuracy* and *attribution of* *accuracy* together support external construct validity. Because of the lack of "golden standard", external validity is examined as to which extend the measured HFI is associated with its exogenous factors such as risk factors and consequences of HFI. In this chapter, the methods used to summarize the latent food insecurity are discussed, followed by exploration on the external validity and dependability of FAST.

Latent Score vs Summative Index

Introduction

To fully use the information provided in polytomous responses, two methods are potentially applicable: 1) constructing a latent food insecurity score by the graded response model (GRM) under the item response theory (IRT) (3); or 2) constructing a summative index.

There are theoretical and practical considerations to be taken into account. Briefly, IRT is a parametric nonlinear factor-analytic approach modeling item-wise response pattern, which is widely used to assess "ability" or "intelligence" in the field of psychometric research (4, 5). Items on the scale have different level of "difficulty" and IRT modeling has the advantage to estimate the latent "ability" by taking into account the item attributes. For food insecurity measurement, items are intended to measure the "severity" on a latent continuum instead of "ability". IRT allows different items reflect different levels of severity, which is more theoretically appropriate because it complies with the theory of "managed process" (6). Therefore, IRT is a more theoretically-sound method and require a few prior assumptions to be met. On the other hand, a summative index is a composite sum score. The underlying theory treats each item as formative measures related to the latent food insecurity, regardless of how items are correlated. Practically, it has the advantage of being simple and more interpretable, especially in the field outside psychometric research.

In the nutrition realm, it is not uncommon to see researchers generate a summative index over polytomous responses and use it to represent the latent insecurity (7, 8). However, no effort has been made on justifying the use of an index over a latent score. This chapter focuses filling the gap by: 1) generating a valid food insecurity latent score from polytomous responses; and 2) comparing the summative index with the latent score on 'correctly' ranking households along their latent continuum.

Methods

IRT assumption

For the IRT method, four core assumptions are required: unidimensionality, monotonicity, local independence, and measurement invariance.

Unidimensionality refers to the fact that the food insecurity scale measures a single latent trait. Mathematically speaking, only one food insecurity latent variable is necessary to account for the inter-item associations in the empirical data (9). Principal component analysis (PCA) was used to detect the number of components among the FAST items. PCA is a mathematical procedure that converts a correlation matrix of a given multivariate dataset to reveal the dominating independent components (10). The eigenvalues calculated from PCA are used to determine the number of unique components. The reported eigenvalues are in descending order indicating the first component contains the most variability in the data and each following component additionally explains less and less remaining variance. A large proportion of variance explained by the first component is expected to support unidimensionality. Because each FAST item was ordered on a 5-point Likert scale, the polychoric correlation matrix was first calculated, on which the PCA was performed. A simulation analysis, known as parallel analysis, was also performed to help make judgment about unidimensionality. Mean simulated eigenvalues was calculated from 1,000 simulations using the same sample size, number of items, means and variances of item response, but a different item correlation matrix that is due to chance alone. Components with observed eigenvalues are considered unique and independent if they are greater than those mean simulated eigenvalues that would get by chance alone.

Monotonicity indicates that the probability of endorsing a response is a monotonically non-decreasing function of the food insecurity latent trait. It means that people with increasing severity of food insecurity have greater proportion to respond to a higher frequency category than people would with less severe food insecurity. This assumption allows ordering households on a food insecurity latent continuum. Monotonicity of each individual item was assessed by a non-parametric method (9), comparing the probability of endorsing a category or above given the sum score of all the items except for the item being examined (known as *restscore*). Minimum size of violation was set at 0.03 per recommendation (9). Minimum size (*minisize*) of *restscore* group was set at a more conservative value of sample size divided by 50, instead of 10 (9), due to the large sample size. The Mokken package from R 2.13.2 (The R Foundation for Statistical Computing) was applied to report the number of monotonicity violations and to plot the observed probability of endorsing polytomous response against *restscore* groups.

Local independence states the independent relationship between responses to any two items conditioning on the underlying food insecurity trait. To check local independence among polytomous items pairs, there are two methods identified: the first is a non-parametric test known as Mantel score test conditioning on the level of latent strata (11), which is an extension of the Mantel-Haenszel procedure with one degree of freedom (12). Like the Mantel-Haenszel methods for dichotomous outcome and exposure, the Mantel score test returns an average association between ordinal responses of two items across several levels of food insecurity strata. The second method is a parametric method using ordered logistic regression of one item on the other controlling for the food insecurity latent. A general ordered logistic regression was applied because the proportional assumption was violated across ordered responses. We reported an average odds ratio and corresponding 95% confidence interval across polytomous responses by fitting partial proportional odds models that best fit the data.

Measurement invariance indicates that the response behavior to each item on the scale should not differ by the respondent's characteristics that are considered exogenous variables of food insecurity, such as respondents' race, education level, and sex, etc. In another word, measurement invariance of a scale indicates an unbiased scale that is understood similarly by different socio-economic groups when they are having similar level of food insecurity. There are also two common ways to evaluate conditional measurement invariance: the item partial correlation method (13) and the extension of logistic odds regression model (14). Likewise, the observed raw summed score was used for as a proxy of the unobserved latent trait in both analyses. The cutoff of considerable significant item partial correlation is 0.1. The logistic regression models the ordered response of each item with the subgroup characteristics conditioning on the raw summed score. Given the large sample size, there is high likelihood to detect statistical significant difference at alpha level of 0.05.

Therefore, a threshold for practical difference is borrowed from psychosocial research (14). A relatively large practically meaningful bias is considered to be an odds ratio (OR) > 2.0 or conversely <0.5. The interpretation of such a cutoff would be on average one socioeconomic group has at least twice the odds of responding to a higher category of that item than the other group, after matching on the overall food insecurity status. Because the majority of the respondents were the participating women (92%), measurement invariance was not examined by respondents' sex. Rather, we estimated an average odds ratio for each item comparing Muslim vs non-Muslim and literate vs illiterate, respectively.

Graded Response Modeling for Latent Score

It would be appropriate to fit graded response model (GRM) to estimate latent HFI score if the four core assumptions are met. In case the local independence is violated which is found quite common, necessary modification is required to improve the fitness of model and to better represent the dependent data. Mplus 6.11 (Muthen & Muthen) was applied for GRM building. The first step, the null GRM (model 0) was fit, ignoring local dependence among items. The modification indices (*MODINDICES*) was requested to return the expected parameter change indices for the pairwise residual correlations, which were fixed at zero in model 0 (15). Secondly, the pairwise item correlation that returned the largest modification indices was included in the next model (model 1) to account for local dependence between that pair of the items. Thirdly, a likelihood ratio Chi-square test (*DIFFTEST*) was conducted between two adjacent nested models that one model (e.g. model 1) included one additional pairwise item correlation than the other (e.g. model 0). Repeat the three steps by including the item pairwise correlation with the next greatest modification index into the model until the likelihood ratio test reached to insignificant level at alpha of 0.05. The final significant model was used to estimate food insecurity latent score.

Comparison between Latent Score vs Summative Index

A summative index was calculated as the total of polytomous responses of the 9 items (SI9). The possible range of the index would be from 0 to 36, with higher index indicating severe food insecurity.

In order to compare index with latent score, scatter plot was used as to examining the correlation. Because individual rank on food insecurity continuum was often not the focus, households were then categorized into four groups: food secure (zero index or lowest latent score), mild, moderate and severe HFI classified based on the tertile cutoffs of non-zero index or non-secure latent score. The raw agreement and the Kappa value were calculated to evaluate agreement in classification between to methods.

The question about "square meals" is reverse-coded in order to be consistent with severity of food insecurity as in other questions. STATA 13.1 (StataCorp, College Station, Texas) was used to perform the aforementioned analyses unless otherwise specified.

Results and Discussion

Table 4.1 shows the distribution of responses on the FAST scale. About 40% of the sample bought rice at least one time in the past 6 months. For the other items, more than 80% of the respondents recalled having no food insecurity related experiences. **Figure 4.1** demonstrated the results from PCA and parallel analysis. The first component had an eigenvalue of 6.04, which accounted for 67% of the variance in the FAST scale. Comparing with the parallel analysis, the observed eigenvalue of the first component was much greater than the simulated eigenvalue, whereas the observed eigenvalue is a little less than simulated value for the second component. Taking into account three conventional cutoff for identification of independent component, including a) observed eigenvalue>1; b) variance explained > 2/3; and c) the observed eigenvalue > simulated eigenvalue, only one primary component stood out in the FAST scale, indicating the unidimensionality assumption was likely met. The monotonicity assumption was also satisfied (**Figure 4.2**) based on the fact that none significant violation was reported.

The Mantel score statistics for pairwise local independence was demonstrated in **Table 4.2**. A value equal or greater than 3.84 implies significant local dependence. The negative scores were brought down by negative bias given the method used (11), indicating underestimated local dependences. Keeping in mind that the values should have been greater than they appeared in table 4.2, we found strong evidence of local dependence among all item pairs, with only one potential exception for the item about frequency of rice procurement (mean Mantel scores statistics=-8.2).

Measurement invariance was checked by respondents' religion and literacy status (**Table 4.3**). The partial correlation indexes showed weak correlation between each item and the respondents' characteristics (| r|<0.1). The rice procurement item had a marginally high correlation of -0.13 between the literacy status. The average odds of endorsing an item was positively associated with being Muslim for "no square meals", "skipping meals", "eating less food", and "worrying about food" (all p<0.05). On the other hand, "no money for food", "worrying about food", and "buying rice often" were less likely reported by literate than illiterate respondents (all p<0.001). However, if applying the practical cutoff of OR> 2.0 or conversely <0.5, none of the items showed severe violation of measurement invariance by their religion and literacy status.

In sum, three out of four assumptions were generally met and the local independence was seriously violated for almost all item pairs. Stepwise graded response modeling was applied to generate a more precise latent food insecurity score by adjusting for pairwise item dependence (**Table 4.4**). After accounting for 15 most influential pairwise correlations, adding more correlation did not improve estimation efficiency as shown from the likelihood ratio test (p-value for model 17=0.07>0.05).

The distribution of the latent score generated from the final GRM model and the summative index were shown in **Figure 4.3** side by side (food secure group was excluded). For any food insecure respondent (any positive response), the latent score ranges from -0.6 to 3.3, with mean ± SD of 0.07 ± 0.78. The range for summative index is from 1 to 31 with mean ± SD of 3.0 ± 4.7. **Figure 4.4** is the scatter plot of the two scores. The smooth curve indicates a non-linear relationship of the two summary scores. A linear relationship held approximately true when the summative index was less than 15. However, the non-linear relationship of individual scores did not prevent the summative index classifying households into 'correct' food insecurity categories as compared with the latent score (**Table 4.5**). The agreement between the two methods, with or without food secure group, was 89% and 78%, respectively. Kappa statistic, a measure of agreement between the two methods taking into account agreement by chance alone, had a value of 0.8 for the entire sample or 0.7 if excluding the food secure group, which was considered as good agreement in the literature (16).

Conclusion

From the preliminary analysis, summative index held the promise to correctly represent the food insecurity categories as compared with the latent score estimated from valid and more sophisticated GRM models. Given the simplicity and validity, the summative index was applied in the rest of the dissertation to examine external validity and dependability of FAST and to associate it with maternal and infant nutritional outcomes.

External Validity

FAST is tested using dichotomous index against qualitative evaluations (1, 17) and individually correlated against selective proxy indicators of poverty, food consumption, adult body mass index (BMI) and child malnutrition under 12 years old (1). In the section, the external validity is examined using the summative index of 9 items (SI9) against predictors identified in the conceptual framework (**Chapter 2 Figure 2.2**). The nutritional consequences are of the interest in this thesis research and are discussed in more detail in later chapters.

Table 4.6 shows the bivariate relationship between selective predictors for physical and economic food access and variables of socioeconomic status (SES). Greater SI9 indicates severer food insecurity. Mean SI9 is lower by 2.2 to 3.1 unit comparing households with land used for food production with households without such resources. Livestock ownership is negatively correlated with food insecurity index. Under the economic access, whether or not husband has a paid job is not associated with SI9, because it is universal that the male has some type of income-earning activities in our study area (99.9%). On the other hand, only 37.2% of the women have a paid job and it is a significant factor to prevent perceived food insecurity. Micro-credit organization participants and loan takers are more likely to perceive food insecurity, which is in line with the expectation that those financial services are targeted on the impoverished. The wealth index (WI) is constructed to represent the overall wealth and SES of each household (18). Per one unit increase in WI (higher WI indicates better wealth), the mean SI9 decreases by 2 and the likelihood of experience food insecurity is reduced by 60%. Other socioeconomic status (SES) variables are individually correlated with the SI9 and probability of food insecurity in the expected way. Likewise, a summative index of the two items (SI2) was calculated for later discussion as the sum of two items: "worry about food" and "buy rice often". The relationship between SI2 with the examined predictors is similar to the relationship between SI9 and predictors.

The above evidences support that SI9 reflects the true access to food at household level. The summative index is an externally valid indicator as tested comparing with potential predictors of household food insecurity.

Dependability

Dependability expects the scale to be responsive to changes in comparator measurements over longitudinal measurements. The JiVitA Cohort Update Survey (JCUS) provides a unique opportunity to examine dependability of FAST. The FAST is conducted between November 2009 and March 2012 at 6 month postpartum (6MP). JCUF is a cross-sectional survey which is conducted between February 2012 and March 2012. The time difference between the two assessments is 1.2 ± 0.6 years. Two items from the FAST, asking about frequency of rice procurement and frequency of worrying about food, are collected at both assessments. As shown in **Table 4.6**, like SI9, SI2 also shows an inverse relationship with better physical and economic assess to food. Likewise, greater SI2 indicates severer food insecurity. Households are classified into three broad groups based on the changes in SI2 overtime: 1) becoming more food secure (Group 1: 16.1%), represented by a decreased SI2 in JCUS from 6MP; 2) unchanged food security status (Group 2: 47.4%), represented by an unchanged SI2; and 3) becoming more food insecure (Group 3: 36.5%), represented by an increased SI2. A subset of questions regarding to household SES are assessed both at enrollment and the JCUS rounds. The change in the proportion of ownership over assets, utility and wall construction is represented in **Table 4.7** by the three food insecurity dynamic groups.

Group 1 is associated with increased ownership of most assets or utility, except for clock (-4.7%), chicken or duck (-8.1%), and slight reduction in the proportion of reported ownership of goat or sheep (-0.2%). More households in group 2 than in group 1 lose their ownership of clock (-4.9%) and chicken or duck (-12.1%). In group 3, households reported no ownership over showcase, clock or any chicken or duck increases to 22.6%, 6.4% and 16.9%, respectively. From group 1 to 3, there is a decreasing trend in the proportion change of ownership over showcase and cattle. Such linear trend is not seen in other assets assessed. When a households reported a different SI2 from the two assessments (group 1 and group 3), responses to FAST items generally alters accordingly to the change in the underlying SES: for households with improved food security (group 1), ownership over assets increased the most or decreased the least; for households with worsened food insecurity (group 3), ownership over assets in general decreased the most or increased the least. However, assets referring long-term living standards, such as ownership over living rooms (=0%), beds (<1%) and electricity availability (<8%) have not shown big change over time. The wall construction has been improved over time in all three groups. Yet, the major change in wall material is seen from a switch from grass, plant leaves or earth to tin or wood plank. The proportion of households with least (no wall) and most ranked wall material (cement brick) has not changed much. The household size increases gently in all three groups from 6MP to the JCUS round.

In sum, nearly half of the households has an unchanged SI2, indicating a likely static food security status (group 2) over a period of 1 to 2 years. The slight change in long-term SES indicators also indicates that the long-term food security status is unlikely changed substantially. However, interpretation of the data with caution is needed because of the following limitations: 1) the selective assets items on JCUS may not exhaustively reflect the true underlying change in SES; and 2) the two items from FAST may not represent the overall food insecurity experience of a given household. Future research with comprehensive and longitudinal measures of HFI and SES should future test the dependability of a behavior-based food insecurity scale.

Summary

The validity was established of using a summative index of the 9-item FAST to reflect latent HFI. Preliminary examination suggests that FAST is externally valid and dependable. Given the large proportion of unchanged responses to a subset of FAST and unsubstantial change in long-term SES over a 1-2 year period, it indicates that HFI assessed by FAST reflect chronic and likely static food security/insecurity status at household level in rural Bangladesh.

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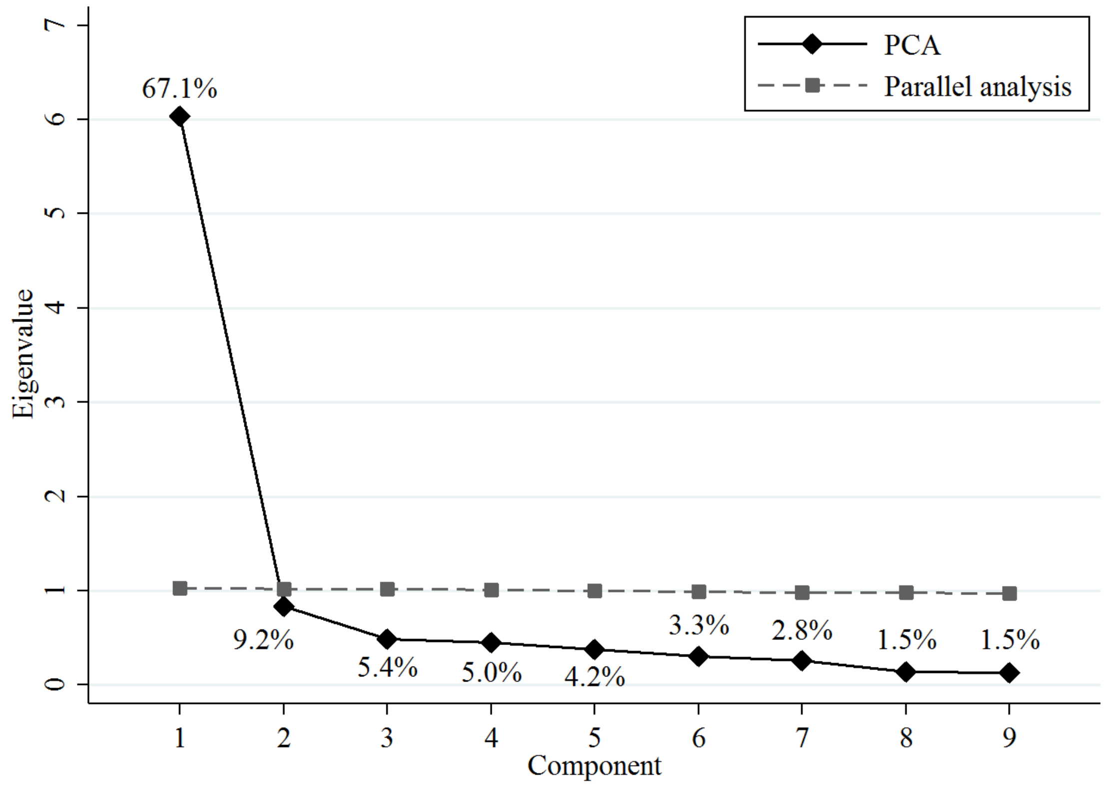
Figures and Tables for Chapter 4

Table 4.1: Distribution of responses to the FAST (N=16,993)[1]

Item	Never		Rarely		Sometimes		Often		Mostly	
No square meals	14460	(85.1)	1165	(6.9)	865	(5.1)	217	(1.3)	286	(1.7)
Have to eat wheat	16032	(94.3)	425	(2.5)	412	(2.4)	94	(0.6)	30	(0.2)
Skip meals	15441	(90.9)	828	(4.9)	559	(3.3)	125	(0.7)	40	(0.2)
Eat less	13725	(80.8)	1033	(6.1)	1528	(9.0)	422	(2.5)	285	(1.7)
No money for food	15182	(89.3)	990	(5.8)	661	(3.9)	130	(0.8)	30	(0.2)
Worry about food	14810	(87.2)	817	(4.8)	884	(5.2)	267	(1.6)	215	(1.3)
Buy rice often	10172	(59.9)	1510	(8.9)	1324	(7.8)	1511	(8.9)	2476	(14.6)
Take food on credit	14561	(85.7)	708	(4.2)	996	(5.9)	398	(2.3)	330	(1.9)
Borrow food	13788	(81.1)	2043	(12.0)	1015	(6.0)	122	(0.7)	25	(0.1)

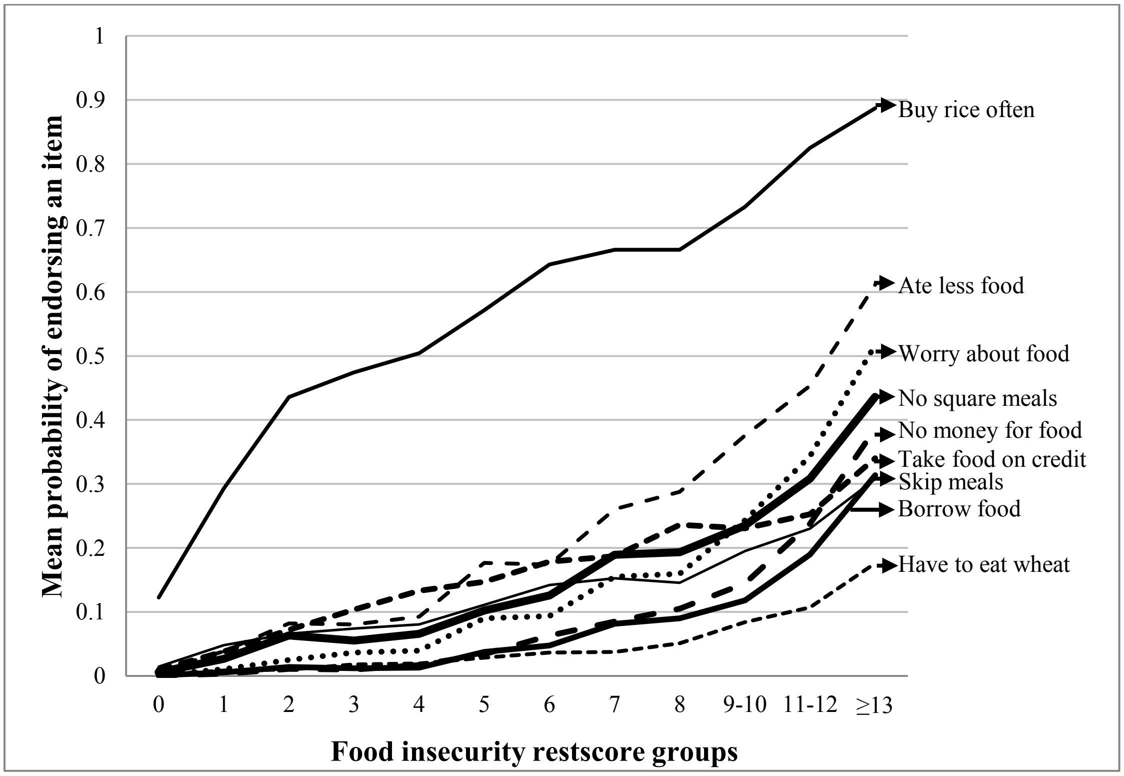
1. n (%) are presented

Figure 4.1: Comparison of observed eigenvalues from principle component analysis and simulated eigenvalues from parallel analysis



Note: Principal component analysis (PCA, solid line) is used to detect the number of independent components within the FAST scale. Observed components are then compared with the components that would be obtained if the correlation among items in FAST are due to chance alone (Parallel analysis, dash line). Proportion of variance explained by each component is labeled in number next to each point.

Figure 4.2: Monotonicity plot of each item on FAST



Note: The question about "square meals" is reverse-coded in order to be consistent with severity of food insecurity as in other questions. Mokken package in the R program is used to plot and examine the monotonicity assumption. None violation is identified therefore this assumption is not validated.

Table 4.2: Mantel score statistics[1] for pairwise items on a given level of food insecurity

	No square meals	Have to eat wheat	Skip meals	Ate less food	No money for food	Worry about food	Buy rice often	Take food on credit	Borrow food
No square meals		10.7	20.3	57.4	25.2	15.8	-30.6	-5.5	19.3
Have to eat wheat			25.6	31.8	25.7	19.6	-13.6	8.3	23.9
Skip meals				46.7	40.5	28.8	-13.8	6.8	30.3
Ate less food					35.6	28.4	-31.8	-3.4	39.2
No money for food						45.1	-6.7	10.3	35.8
Worry about food							-9.9	5.5	30.7
Buy rice often								12.7	27.5
Take food on credit									26.5
Borrow food									

Note: A Chi-square value equal or large than 3.84 is significant at 0.05 level.

1. The Mantel score statistic (Q_{MS}) is calculated using the following formula (11):

$Q_{MS} = \frac{\sum_k [\sum_r \sum_c u_r v_c n_{rck} - E(\sum_r \sum_c u_r v_c n_{rck})]}{[\sum_k var(\sum_r \sum_c u_r v_c n_{rck})]^{1/2}}$, where

$E(\sum_r \sum_c u_r v_c \, n_{rck}) = \frac{(\sum_r u_r n_{r+k})(\sum_c v_c n_{+ck})}{n_{++k}}$, and

$var(\sum_r \sum_c u_r v_c \, n_{rck}) = \frac{1}{n_{++k}-1}\left[\sum_r u_r{}^2 n_{r+k} - \frac{(\sum_r u_r n_{r+k})^2}{n_{++k}}\right] \times [\sum_c v_c{}^2 n_{+ck} - \frac{(\sum_c v_c n_{+ck})^2}{n_{++k}}]$

u_r *and* v_c are ordered responses of two items and r and c ranging from 1 to 5;

k is the food insecurity tertile strata. k=1,2,3 representing mild, moderate and severe insecurity;

n_{rck} is the number of respondents have answering two items r and c;

$n_{+ck}, n_{r+k},$ *and* n_{++k} are the sum for column, row and total number of respondents at k^{th} strata.

Table 4.3: Results of measurement invariance assumption check

	Religion (Muslim vs non-muslim)				Literacy (literate vs illiterate)			
	Partial corr. index[1]	Average OR[2]	95%CI	p-value	Partial corr. index	Average OR	95%CI	p-value
No square meals	-0.002	1.16	(0.96, 1.40)	NS	-0.04	1.04	(0.92, 1.17)	NS
Have to eat wheat	-0.03	0.79	(0.62, 1.01)	NS	-0.03	1.17	(0.99, 1.38)	NS
Skip meals	-0.002	1.35	(1.07, 1.72)	0.01	-0.05	1.00	(0.86, 1.18)	NS
Ate less food	0.01	1.69	(1.40, 2.04)	<0.001	-0.07	0.92	(0.82, 1.03)	NS
No money for food	-0.01	1.22	(0.97, 1.53)	NS	-0.09	0.69	(0.60, 0.81)	<0.001
Worry about food	0.00	1.25	(1.01, 1.54)	0.04	-0.09	0.73	(0.63, 0.85)	<0.001
Buy rice often	-0.03	0.95	(0.82, 1.11)	NS	-0.13	0.73	(0.67, 0.80)	<0.001
Take food on credit	-0.01	1.03	(0.86, 1.23)	NS	-0.03	1.06	(0.94, 1.20)	NS
Borrow food	-0.01	1.12	(0.96, 1.32)	NS	-0.03	1.03	(0.93, 1.15)	NS

1. Item partial correlation is calculated per the following formula (13):

$r_{iS \cdot T\infty} = \frac{r_{iS} - r_{iT\infty} r_{T\infty S}}{\sqrt{1-r_{iT\infty}^2}\sqrt{1-r_{T\infty S}^2}}$, where

r_{iS} is the Spearman correlation between item responses and subgroup;

$r_{iT\infty}$ is the correlation between the item and the restscore as introduced above;

$r_{T\infty S}$ is the correlation between the total raw sum and subgroup.

The cutoff of considerable significant item partial correlation is 0.1.

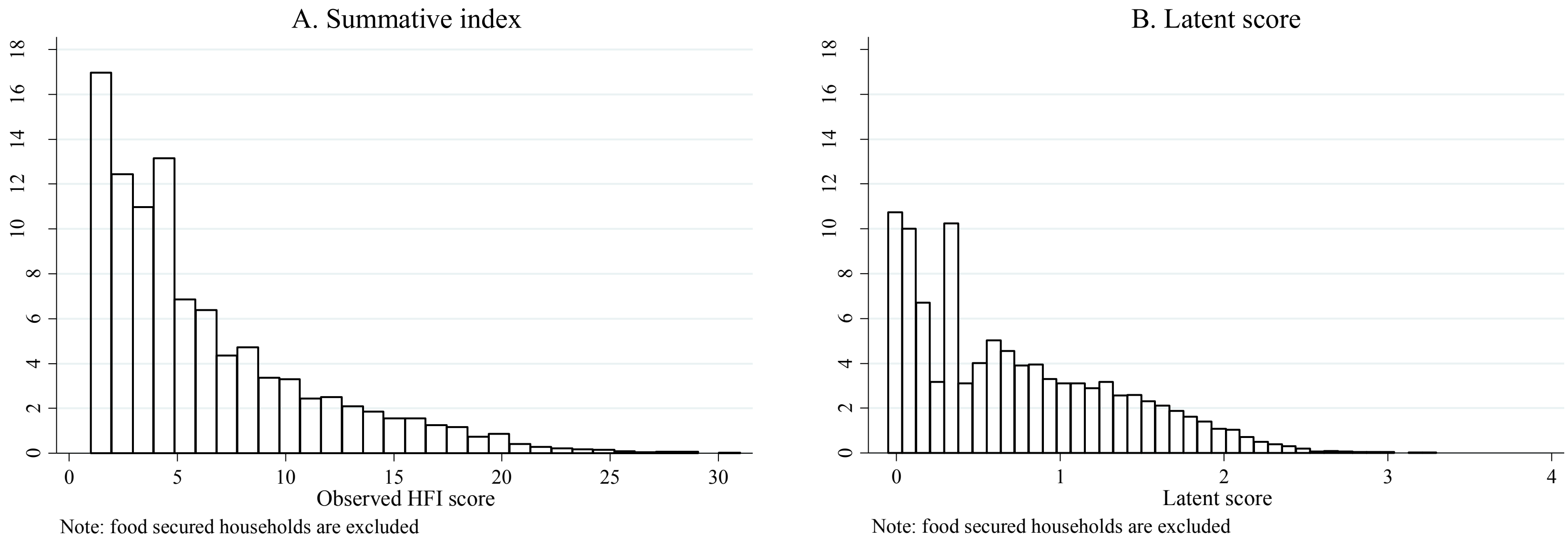
2. Generalized ordered logistic regression methods is used to estimate ORs given the violation of proportional odds assumption. The average ORs is estimated from an iterative process for identifying the partial proportional odds model that best fit the data (“autofit” option is applied using STATA/SE13.1)

Table 4.4: Stepwise graded response models to estimate latent food insecurity score

Model Index	Stepwise model building	Highest modification index	Chi-square for difference testing [model j vs model (j-1)]	p-value
0	Local independence	1418.2	-	-
1	Model0 + (less with sqml)	595.3	753.8	<0.001
2	Model1+ (rice and credit)	365.9	354.8	<0.001
3	Model2+ (borrow and credit)	235.9	240.5	<0.001
4	Model3 + (less and skip)	184.5	209.7	<0.001
5	Model4+(skip and sqml)	85.6	142.5	<0.001
6	Model5+ (wheat and sqml)	96.9	62.1	<0.001
7	Model6+ (less and wheat)	72.0	82.2	<0.001
8	Model7+ (skip and wheat)	64.0	55.4	<0.001
9	Model8+ (borrow and rice)	16.9	41.6	<0.001
10	Model9+ (skip and worry)	10.0	24.3	<0.001
11	Model10+(worry and sqml)	8.9	14.1	<0.001
12	Model11+ (credit and wheat)	8.0	6.7	0.01
13	Model12+ (borrow and nomon)	4.5	9.3	0.002
14	Model13+ (nomon with skip)	6.1	4.2	0.04
15	Model14+ (borrow and worry)	4.7	5.4	0.02
16	**Model15+ (credit with sqml)**	**4.0**	**5.2**	**0.02**
17	Model16+ (rice and wheat)	1.0	3.2	0.07
18	Model17+ (rice with sqml)	0.7	1.1	0.30

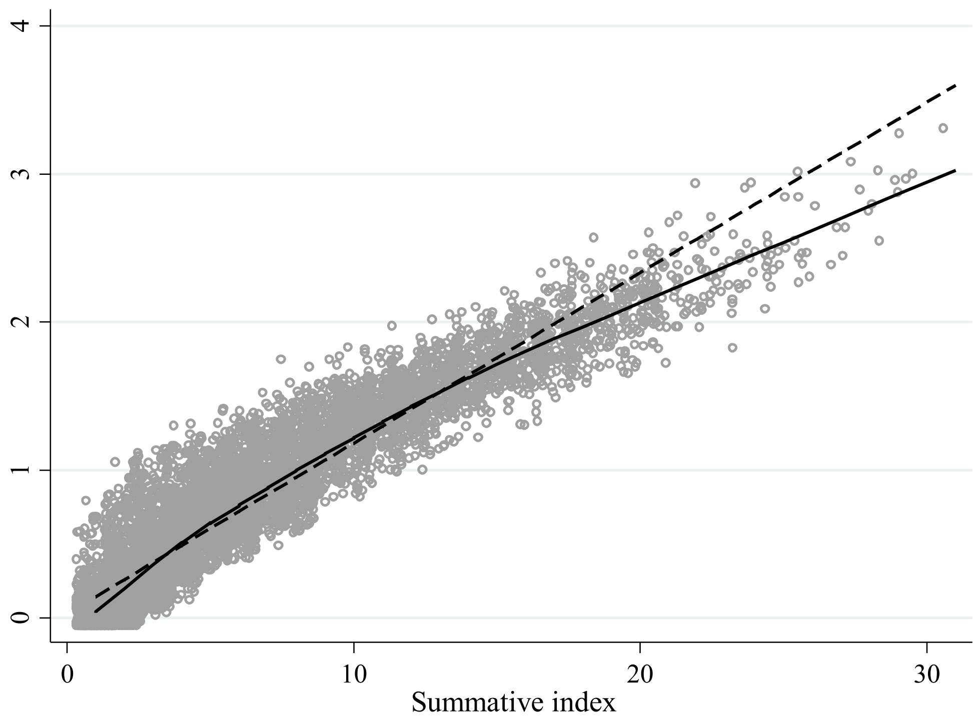
Note: Model 16 is used to estimate the latent score that corrected for local dependence, because model 17 is no longer significantly improving latent estimation from model 16 (p=0.07).

Figure 4.3: Distribution of summative index and latent score (food secure household are excluded)



Note: A. Distribution of summative index; B. Distribution of latent score.

Figure 4.4: Relationship between summative index and latent score



Note: Grey circles are the scatter plot of summative index and latent score. Solid line is the smooth curve between the two variables. Dash line is the linear prediction of latent score given summative index.

Table 4.5: Cross tabulation of food insecurity tertiles defined by raw summed score and estimated latent from the local dependence adjusted graded response model

			Summative index tertiles				
			Food secure	Food insecure			
				Mild	Moderate	Severe	**Total**
Latent score tertiles		Food secure	8513	0	0	0	**8513**
	Food insecure	Mild	0	2762	553	0	**3315**
		Moderate	0	630	1389	321	**2340**
		Severe	0	30	296	2499	**2825**
		Total	**8513**	**3422**	**2238**	**2820**	**16993**

For the entire sample:

$$\%\ of\ agreement = \frac{8513+2762+1389+2499}{16993} = 89.2\%$$

Excluding food secure group:

$$\%\ of\ agreement = \frac{2762+1389+2499}{16993-8513} = 78.4\%$$

Kappa statistic is 0.84 between the two methods, if including the food secure group.

Kappa statistic is 0.67 between the two methods, if excluding the food secure group.

Table 4.6: External validity comparing FAST summative index with predictors of household food insecurity[1]

	N	Summative index of two items (worry + rice) Beta coef. (95%CI)	Summative index (all 9 items) Beta coef. (95%CI)	Odds of food insecurity[2] OR (95%CI)
Physical access				
Land ownership, yes vs no				
Crop cultivation	11825	-1.5 (-1.5, -1.4)***	-3.0 (-3.2, -2.9)***	0.3 (0.2, 0.3)***
Homegarden	11849	-1.2 (-1.3, -1.1)***	-2.4 (-2.7, -2.2)***	0.3 (0.3, 0.3)***
Fruit and bamboo	11489	-1.0 (-1.1, -0.9)***	-2.1 (-2.3, -1.9)***	0.4 (0.4, 0.4)***
Fish pond	11558	-1.1 (-1.2, -1.0)***	-2.2 (-2.4, -2.0)***	0.4 (0.3, 0.4)***
Livestock ownership, yes vs no				
Cattle	12064	-1.2 (-1.2, -1.1)***	-2.3 (-2.5, -2.1)***	0.3 (0.3, 0.4)***
Goat	12065	-0.3 (-0.4, -0.3)***	-0.8 (-1.0, -0.5)***	0.7 (0.7, 0.8)***
Chicken or duck	17403	-0.9 (-0.9, -0.8)***	-1.8 (-1.9, -1.6)***	0.5 (0.4, 0.5)***
Chicken	12054	-0.7 (-0.8, -0.6)***	-1.4 (-1.6, -1.2)***	0.6 (0.5, 0.6)***
Duck	12063	-0.8 (-0.9, -0.7)***	-1.6 (-1.8, -1.4)***	0.5 (0.5, 0.5)***
Economic access				
Husband has a paid job, yes vs no	12064	1.2 (-0.8, 3.2)	1.9 (-3.0, 6.8)	1.2 (0.2, 8.4)
Women has a paid job, yes vs no	12065	-0.04 (-0.11, 0.03)	0.1 (-0.1, 0.3)	0.92 (0.85, 0.99) **
Household is a member of micro-credit organizations, yes vs no	12063	0.7 (0.6, 0.7)***	1.5 (1.3, 1.7)***	1.8 (1.7, 2.0)***
Taking loans, yes vs no	4835	0.4 (0.2, 0.7)***	1.0 (0.4, 1.5)***	1.7 (1.4, 2.0)***

(Table 4.6 cont'd)

	N	Summative index of two items (worry + rice) Beta coef. (95%CI)	Summative index (all 9 items) Beta coef. (95%CI)	Odds of food insecurity[2] OR (95%CI)
Other socioeconomic variables				
Wealth index	17386	-0.9 (-0.9, -0.8)***	-1.8 (-1.9, -1.8)***	0.4 (0.3, 0.4)***
Household size	17400	-0.1 (-0.1, -0.1)***	-0.2 (-0.2, -0.1)***	0.9 (0.9, 0.9)***
Ownership of durable assets				
Showcase	17403	-1.3 (-1.3, -1.2)***	-2.8 (-3.0, -2.7)***	0.3 (0.2, 0.3)***
Clock	17403	-1.0 (-1.0, -0.9)***	-2.2 (-2.4, -2.1)***	0.4 (0.4, 0.5)***
Bed	17403	-1.5 (-1.8, -1.3)***	-4.1 (-4.8, -3.4)***	0.3 (0.2, 0.5)***
Living rooms	17403	No variation	No variation	No variation
Mobile phone	17402	-1.0 (-1.1, -0.9)***	-2.4 (-2.5, -2.3)***	0.3 (0.3, 0.4)***
Electricity	17402	-0.8 (-0.8, -0.7)***	-1.8 (-2.0, -1.6)***	0.5 (0.4, 0.5)***
Construction of wall	17375			
No walls		2.9 (0.9, 5.0) **	8.6 (3.6, 13.7) **	(Too few observations)
Grass		1.6 (1.5, 1.6)***	3.4 (3.2, 3.6)***	3.9 (3.5, 4.4)***
Bamboo/betel nut plants/earth		1.1 (1.0, 1.1)***	2.4 (2.2, 2.6)***	3.4 (2.1, 2.7)***
Tin/Wood plank (reference)		-	-	-
Cement and brick		-0.9 (-1.0, -0.8)***	-1.9 (-2.1, -1.7)***	0.2 (0.2, 0.3)***

Note: 1. significance of the bivariate analyses is denoted as: ***, $p<0.001$; **, $p<0.01$; No star, not significant at 0.05 level; 2. food insecurity is defined as non-zero summative index;

Table 4.7: Change in socio-economic status by change in summative index of two items

	Group 1 Became more secure Diff(JCUS-6MOP)<0	Group 2 Unchanged food security status Diff(JCUS-6MOP)=0	Group 3 Became more insecure Diff(JCUS-6MOP)>0
Proportion reported ownership of			
Showcase	14.9	10.5	-22.6
Clock	-4.7	-4.9	-6.4
Bed	0.6	0.3	0.9
Living rooms	0.0	0.0	0.0
Mobile phone	33.6	21.2	26.5
Electricity	5.1	7.6	4.6
Chicken or duck	-8.1	-12.1	-16.9
Goat/ Sheep	-0.2	1.2	0.0
Cattle	4.0	3.0	2.3
Fishpond	11.8	13.3	9.0
Construction of wall			
No walls	0.1	0.0	0.1
Grass	-8.7	-3.0	-8.0
Bamboo/betel nut plants/earth	-6.3	-3.2	-4.6
Tin/Wood plank	12.9	2.8	11.3
Cement and brick	1.2	3.4	1.3
Household size	0.5 ± 1.4	0.3 ± 1.8	0.2 ± 2.0

CHAPTER 5: Maternal Dietary Quality during Pregnancy and Early Postpartum Period in the Context of Household Food Insecurity in Rural Bangladesh

Abstract

Household food insecurity (HFI) is considered a cause of chronic malnutrition in rural South Asia, although little is known about the degrees to which long-term dietary patterns of women during pregnancy and lactation covary by reported level of food security. This relationship was examined during a micronutrient intervention trial in rural northern Bangladesh. We prospectively assessed diet by a 7-day food frequency questionnaire (FFQ) among a cohort of 14,600 mothers in the 1st and 3rd trimesters of pregnancy, and at 3 months postpartum, covering an approximate one-year period. A HFI index was created from a 9-item standardized tool, asked at 6 mo postpartum. At each time and in all seasons, the variety with which ten major food groups were consumed in the diet, also reflected in a women's dietary diversity score (WDDS), decreased progressively with poorer food security. In the bivariate analyses, HFI was associated with a significant decrease in the likelihood of consuming all ten food groups that were used for the WDDS calculation. Although declining with HFI ($p<0.01$), the proportion of women reporting weekly intake of non-rice staples, other fruit and vegetables and fish changed little and remained high, above 80%, across the gradient of HFI. Vegetable oil consumption was universal and unaffected by HFI status. In a multivariate analysis adjusting for maternal and household-level socioeconomic variables, food insecure women were at a steadily increased risk not having dairy, eggs, meat, and fish in their diet during preganncy and lactation with poorer food security. On the other hand, food insecure women were more likely to have consumed legumes and nuts as well as dark-

green leafy vegetables. Antenatal and early postnatal dietary quality decreased in a dose-response way with worsening food security in rural Bangladesh, driven by lower intakes of animal-source foods throughout all seasons. Policies that reduce food insecurity may lead to increased intakes and demand for animal-source foods by pregnant and lactating women in rural Bangladesh.

Introduction

Food security "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (1). In 2010, food insecure population who has limited access to sufficient food is estimated to be 870 million people worldwide, with more than one third populated in the South Asia area (1).

Under food insecurity, increased nutrition requirement during pregnancy and lactation has placed women at greater risk to coexisting micronutrient deficiencies (2-5). Optimal micronutrient status is essential for women during prenatal and postnatal period, which predicts not only women's own mortality and health outcomes (6, 7) but also offspring's mortality growth, development and even risk of chronic diseases (6-8). Although in theory pregnant or lactating women should consume more nutrition and energy-dense food, in practice, women from low- middle-income countries are typically under cereal-based low fat diet, which has low micronutrient content (9). Rural Bangladeshi women, for example, are facing not only economic and but also sociocultural barriers to the food access (10-12). Living under food scarcity, mothers were likely to compromise their own calorie intake (13, 14) and dietary diversity (15) to ensure adequate nutrition of her husband and young offspring. Despite evidences linking socioeconomic wellbeing and maternal dietary intake (16-18), there is little data on how women's dietary quality responds to the severity of household food insecurity during pregnancy and lactation, a period when food restriction is commonly practiced (19, 20).

To address this question, prospective maternal dietary data collected from early pregnancy to early lactation was used from a large prenatal supplementation trial in rural Bangladesh (21). Household food insecurity assessed at 6 month postpartum was linked with women's dietary diversity score (WDDS), calculated as the total number of food groups consumed by individual woman at 1^{st} and 3^{rd} trimester during pregnancy and 3 mo postpartum. WDDS is a commonly used indicator for dietary quality and it is a good predictor for women's micronutrient adequacy (22, 23). We further investigated which food groups contribute to the observed low WDDS, if any, at different level of HFI. The result from this study is expected to provide implication on food and nutrition policy improving maternal diet during those critical physiological phases.

Methods

Study area and population

Women involved in this current study had participated in a large antenatal multiple micronutrient supplementation trial in Gaibandha District in rural northwestern Bangladesh, coving an area of ~435 square km with a population of ~650,000. Married women of reproductive age (13-45 years) were enrolled in a home-based pregnancy surveillance. After pregnancy was confirmed by a urine test, newly pregnant women were consented to participate in the trial in their first trimester and usually a week after recruitment, participants started to receive a daily supplement of either 15 micronutrients or folic acid and iron alone based on cluster randomization through 12 weeks postpartum. Participants were in the 3rd trimester and 3 mo postpartum, during which their usual dietary intake were assessed. Women were asked about their breastfeeding practices at 3 mo postpartum, including whether still breastfed the baby and the intensity of breastfeeding practice. At 6 mo postpartum, a 9-item household food security scale was asked to assess retrospectively the chronic status of household food insecurity.

Household and women's characteristics

After consent was acquired, women were revisited at home asked about age, pregnancy history, education, religion, household size, household socioeconomic status via a structured questionnaire. Women's mid-upper arm circumference (MUAC) was measured three times on the left arm in 1st trimester at enrollment with an insertion tape and the median value was used as the representative measure. The dependency ratio was calculated as the total number of people aged 0-12 and aged over 50 years living in the family divided by the total number of people aged 13-49 years. Household characteristics included dwelling characteristics, ownership of durable assets and agricultural resources, all of which were used to calculate the wealth index according to a previously published methodology (24).

Women's dietary diversity scores (WDDSs)

In the 1TM and 3TM in pregnancy and 3MP in lactation, women's usual diet by a 7-day FFQ was assessed. Frequency of consumption of 32 food items during the past 7 days was asked to participating women. The 32 food items or food groups were then grouped into

11 food groups according to the FAO recommendations (25), namely non-rice starchy staples, dark green leafy vegetables (DGLV), vitamin-A rich fruit and vegetables (VAFV), other fruit and vegetables, legumes and nuts, organ meat, meat, fish, eggs, dairy and vegetable oil. A dichotomous consumption variable of whether the woman had consumed any item within each food group was created. Women's dietary diversity score (WDDS) was calculated as the sum of the number of the dichotomous consumption variable for each food group excluding oil, ranging from 0 (no food group in the past 7 days) to 10 (maximum diversity).

Household food security

The food security scale we used was developed and validated by the Food and Nutrition Technical Assistance Project in Bangladesh (26). It consisted of 9 items covering key domains to reflect household food insecurity from anxiety over food acquisition (worrying about food) to reduction in food quality and/ or quantity (eating square meals, eating wheat when rice is preferred, skipping meals, eating less food) and other behaviors or strategies to augment resources under household food scarcity in the context of rural Bangladesh (having no money to buy food, rice purchasing, taking out a loan from shops or borrowing money to buy food). Participating women were asked to recall the frequencies of the above 9 situations in the past 6 months on a 5-point Likert scale. The question about "square meals" was reversely coded in order to be consistent with higher frequency indicating severer food insecurity as represented in other questions. A household food insecurity index (HFII) was created by summing the indexed frequency of all nine items. Households with no reported food insecurity experiences (HFII=0) are classified as food secure and the rest of the households were categorized into mild (1≤HFII≤3), moderate (4≤HFII≤7) and severe groups (8≤HFII≤36) on the tertile cutoffs of all non-zero HFIIs.

Seasonality

At each maternal diet follow up, six standard seasons were defined based on FFQ assessment date using the Bangladeshi calendar starting from the middle of December for every two months (27), namely winter, spring, summer, early Monsoon, late Monsoon and autumn.

Statistical analysis

All of results were reported by HFI index category, where HFI is treated as a categorical variable. The one-way analysis of variance, or ANOVA test, was used to test equal means of continuous covariates across categorical HFI groups for postpartum weeks at each assessment, women's age, mid-upper arm circumference (MUAC) at early pregnancy, household size, dependency ratio, wealth index, and WDDSs at three assessments. Chi-square tests were used to examine the relationship between HFI groups and categorical variables, such as Muslim vs other religions, whether or not women had any schooling, and whether or not women consumed each food group. Pair-wise T-test was used to examine whether WDDSs consumed by the same women changed over longitudinal assessments. Logistic regression analyses were used to estimate the odds of consuming each food group by comparing women from food-insecure households with women living with food security (reference). The bivariate logistic regression only included HFI groups and binary outcome of whether or not a food group is consumed. In the multivariate logistic models, we further included maternal and socioeconomic variables that were significantly associated with both HFI and WDDSs. P-values less than 0.05 was considered as significant. Because of multiple comparison among likely correlated outcomes, we also applied a Bonferroni correction with cutoff at 0.001, which is 0.05 divided by 33 the total number of food group outcomes examined (11 food groups times 3 assessments). Data were analyzed using STATA/SE 13.1 (StataCorp, College Station, Texas).

Results

Women with singleton pregnancy who had complete data on household food security and dietary assessment were included in the analysis. Out of 18,841 participating women, 162 (0.9%) had twins; 402 (2.1%), 1,981 (10.5%) and 923 (4.9%) had missing data in the FFQ at 1st, 3rd trimester and 3 mo postpartum, respectively; and 773 (4.1%) had missing data in the food security scale. The final sample size in the analysis was 14,600 (77.5%). Among included households, 7,346 (50.3%), 2,936 (20.1%), 2,241 (15.4%) and 2,077 (14.2%) were food secure, or mild, moderate, severe HFI, respectively.

Table 5.1 presents the distribution of some key descriptive maternal and household variables by HFI status. The gestational week during which women were assessed by the food frequency questionnaire did not differ by HFI groups in 1st (1TM) and 3rd trimester (3TM) (both $p>0.05$). However, poorer food security was associated with a few days delay in FFQ assessment at the 3 mo postpartum (3MP) follow up ($p<0.001$). At 1TM, women were older in the severe HFI group. Maternal MUACs (mean ± SD) linearly decreased from 24.0 ± 2.4 cm among the food secure women to 23.0 ± 1.9 cm among those from the severe HFI group. Subjects were living in a Muslim-dominant neighborhood (>90%), yet the distribution of Muslim vs non-Muslim religion was not equal across HFI status, with mild HFI group reported more Muslim proportion of 93.3% and severe reported the lowest of 90.3% ($p<0.01$). The proportion of women who reported primary or higher education dropped progressively from 85.2% in food secure group to 76.8, 68.1, 53.5% in the mild, moderate and severe HFI group, respectively ($p<0.001$). Household characteristics, including household size, dependency ratio and wealth index were also significantly and differently distributed across the food security categories (all $p<0.001$).

With increased intensity in HFI, women's dietary diversity scores (WDDSs) decreased linearly at all three assessments (**Table 5.2**, all $p<0.001$). Comparing women from food secure households (6.2 ± 1.7 at 1TM, 6.3 ± 1.7 at 3TM), women living with severe HFI had a lower average WDDS by about 1 food group (5.3 ± 1.6 at 1TM, 5.3 ± 1.7 at 3TM). Regardless of HFI status, on average there was 0.1 ± 1.9 more food groups consumed at 3TM than at 1TM, which reaches to significance level for the food secure, mild and moderate insecure women (all $p<0.001$) but not for the severely insecure women ($p=0.38$). WDDSs at 3TM were much smaller by about 0.7 ± 1.7 than the average score during pregnancy (all $p<0.001$). The differences between longitudinal WDDSs were consistent across HFI groups comparing two assessments in pregnancy ($p=0.13$) and comparing the postpartum vs gestational assessments ($p=0.24$). The mean WDDSs by season and by HFI were presented in **Figure 5.1**. Though there were seasonal variations, the significant decrease in WDDSs by HFI status was observed in all 6 seasons at all three assessments (all $p<0.001$).

In order to see which food groups contribute to the decrease trend in WDDSs, the proportion of any consumption of each food group was examined by HFI category (**Figure 5.2**). Vegetable oil consumption was universal regardless of HFI status (1TM: $p=0.55$; 3TM:

p=0.34; 3MP: p=0.69). The proportion with which women reported any weekly intake of all 10 other food groups progressively decreased by HFI gradient (all p<0.01), excpet for DGLV consumption at 3MP (p=0.15). On average, the biggest dicrepency in proportion of any consumption reported by severely food insecure women comparing with that reported by food secure women were found in dairy (Δ=18.8%), meat (Δ=16.4%), eggs (Δ=16.1%), legumes and nuts (Δ=10.4%) and VAFV (Δ=9.6%). Although declining with HFI (p<0.01), the proportions changed little and remained high above 80% for other fruit and vegetables (97 to 94%), non-rice starchy staples (92 to 87%), and fish (90 to 82%) by the gradient of HFI. DGLV is consumed by about 70% and 50% women during pregnancy and lactation.

Table 5.3 and 5.4 summarized the results from bivariate and multivariate logistic regressions, respectively. In the unadjusted models (table 5.3), HFI was associated with reduced odds of consuming all food groups except for vegetable oil. With increasing severity of HFI, the mean odds ratio comparing the food secure reference (OR=1.00) decrease progressively in most plant-source food groups with exception in DGLV and more obviously in all animal-source food groups. In the adjusted models, controlling for women's age, postpartum week at assessment (for the 3 mo postpartum assessment only), women's MUAC at 1TM, education, religion, FFQ assessment season, household size, dependency ratio, and wealth index, women from households with mild HFI were 15% (95%CI: 6-7%, 22%) less likely to consume dairy during pregnancy in comparision with their food secure peers. For women in the moderate HFI group, in addition to less dairy intake, the reduced likelihood in food consumptions was also observed in meat (OR=0.89, 95%CI: 0.80, 0.99) and eggs (OR=0.86, 95%CI: 0.77, 0.95) at 1TM and fish (OR=0.83, 95%CI: 0.70, 0.98) at 3TM, respectively. Among women living with severe HFI, all major animal-source foods, namely fish (OR=0.67-0.82), eggs (OR=0.79-0.83), dairy (OR=0.71-0.78) and meat (OR=0.78-0.84) were significantly less likely being consumed compared with reference women. Interestingly, legumes and nuts were more likely consumed by moderately and severely insecure women at early pregnancy (both ORs=1.20, 95%CI: 1.07-1.08, 1.33-1.34) and by severely insecure women at late pregancy (OR=1.12, 95%CI: 1.00, 1.26). Other food groups that was more likely consumed by food insecure women were organ meat and DGLV; however, both were less consistently seen across HFI groups: the former was only observed among mildly insecure women at 1TM (OR=1.16, 95%CI: 1.01, 1.33) and the latter only among severely insecure women at 3MP (OR=1.24, 95%CI: 1.11, 1.39) (table 5.4). Though attenuated from the unadjusted models for animal-source food groups, the decreasing trend in odds ratios by HFI gradient are generally held true. However, a reversed trend was seen in the mutivariate models for some plant-source food groups (OR for mild, moderate and severe group), such as legumes and nuts at 1TM (OR=1.08, 1.20, 1.20) and 3TM (OR=1.01, 1.02, 1.12) and DGLV at 3TM (OR=1.01, 1.02, 1.06) and 3MP (OR=1.03, 1.06, 1.24). Compared with the reference group, none-rice staples were 34% (95%CI: 21%, 45%) and 40% (95%CI: 26%, 51%) less likely consumed by women in the severe HFI group at 3TM and at 3PM. The odds ratios of none-rice staples remained insignificant for all otherwise comparisons. Taking into account multiple group comparison and applying a more conservative cutoff of significance (0.05/33=0.001, where 33 is the # of individual regressions), reduction in consumption of dairy, meat, fish, eggs, and non-staple food remains significant.

Discussion

In this study, we found that the reported household food insecurity (HFI) is dose-responsively associated with lower women's dietary diversity scores (WDDS) at 1st and 3rd

trimester and at 3 mo postpartum in rural Bangladesh. To our knowledge, this is the first study to longitudinally examine the relationship between HFI and women's dietary quality throughout pregnancy to early lactation. Women's restricted dietary diversity is mostly driven by reduction in animal-source food consumption, which is in line with other studies. The inverse correlation between the household food insecurity index assessed by similar scales and dietary diversity of non-pregnant and non-lactating women was observed in resource-limited areas (28-31). Despite differences in methods used for grouping foods, the frequency of meat, fish and poultry consumption is significantly lower (30, 31) among women from food insecure households than those from food secure households. Yet, inconsistent finding was also reported, for example the null association between HFI and food group consumption was seen in one study with smaller sample size (29).

Household's economic access to food likely plays as a major mediator for the observed association between HFI and WDDS. Strong association between the severity of perceived food insecurity and reduced total food expenditure was seen in resource-poor settings (32). On the other hand, dietary diversity is closely linked with per capita total expenditure (16, 33) and per capita total food and non-grain food expenditure (16, 34) in Bangladesh. When food expenditure takes the majority of the budget in rural Bangladeshi households (35), the poor is more motivated to spend money on staple food, which is relatively more affordable, to ensure energy intake rather than non-staple food for better quality food (15).

After adjusting for variables known predictors for economic access to food, such as wealth index, there was still significant, though extenuated, association between HFI and food group intake. Given the large sample size and consistent results across three longitudinal assessments, the possibility of observing an association solely due to random errors is small, indicating HFI influences maternal food consumption partially through pathways other than economic access to food. Community-level characteristics that predict coping mechanisms and consumption behaviors may be the unmeasured factors to explain the residual variation. For example, the easiness of social strategies for food augmentation in Bangladesh, such as borrowing food and shopping for credit (36, 37), are found associated with social capital, a measure of social trust and community reciprocity. Data have shown that comparing with community with low social capital score, community with higher social capital almost halved the probability of households experiencing food insecurity (38-40). On the other hand, physical barriers for food acquirement from market may additionally contribute to the unexplained perceived HFI and low dietary quality, including poor infrastructure (41, 42), inadequate logistics for food distribution (43) and market imperfections (44). Future studies are required on investigating whether community-level characteristics would plausibly explain the remaining association between HFI and women's dietary quality that cannot be explained by predictors for economic access to food at household level.

Comparing with their dietary quality during pregnancy, women had a lower average WDDS when they entered lactation stage, which may be explained by a stricter rule of food restrictions for postnatal women. Rural Bangladeshi culture links certain nutritious foods, such as fish, beef, eggs and leafy vegetables, with either potential source of 'pollutants' or threat to dry out breast milk during lactation (11, 12, 20). In our data comparing postnatal with prenatal period, women reported any consumption of DGLV, dairy, eggs, legumes and nuts, and VAFV have dropped consistently across all HFI groups by 15%, 14%, 12%, 11%

and 8% (see data in **Appendix 5.1**). The reduction in percentage for fish and meat were only 3% and 2%, respectively (Appendix 5.1), probably due to the restriction of flesh meat are more for the beginning postpartum weeks than for 3 month after birth (12).

One limitation of this study is that we do not have direct measures for energy intake. Both WDDS (28-31) and energy intake (45-47) are negatively correlated with HFI and energy is positively correlated with dietary variety and nutrient adequacy (23, 48); therefore, the independent association between HFI and food group intake is likely being overestimated if not controlling for energy intake. In our study, we are unable to fully control for the confounding effect of energy intake but we did include a proxy indicator, women's MUAC, which has shown its promise to reflect women's chronic energy deficiency under emergent food insecurity (49-51). Second, the food frequency questionnaire we used did not include portion size. It is unclear whether the quantity of food intake also varies linearly by HFI gradient. In our data with exceptions in organ meat, DGLV and VAFV, the frequency consumed, if any, of all animal source foods and other plant-source foods showed significant decreasing trend from food secure group to severely insecure group (**Appendix 5.2**). Though, the median frequency of consumption (if reported any) was low for most food groups (with exception in non-rice staple, other FV and fish) for only 1-2 times per week (**Appendix 5.3**). The quantity of food consumption may also decrease linearly by HFI groups, but given low frequency and likely small amount consumed each time (23), overall women in rural Bangladesh have restricted protein and micronutrient intake, which was commonly observed in South Asia (9). Comparing the characteristics of included with excluded households (**Appendix 5.4**), there was no statistically differences in the distribution of continuous wealth index and maternal education. However, more excluded households were in the low wealth index tertile and the mean HFI index was also slightly higher in the excluded sample, indicating the included households might represent higher SES.

Another limitation is that the HFI is retrospectively assessed at 6 mo postpartum. Because of the lack of temporality in our data, we cannot confirm causality between HFI and low dietary intake during pregnancy and lactation. However, as we found in chapter 4 and from other studies, HFI in rural Bangladesh seems to be stable at least for 1-2 years (52). A one-time HFI assessment recalling a relatively long period of time may be a valid proxy for chronic HFI in this part of the world, though future researches with longitudinal HFI measures are required to test this assumption.

Conclusion

Despite the recognized limitations, we found that antenatal and early postnatal dietary quality is lower in a dose-response way by household food insecurity in rural Bangladesh, mostly driven by decreasing intake of animal source foods. Though dark-green leafy vegetable and vitamin A rich vegetables are actively promoted to fight micronutrient deficiency, our data provide evidences on the indifference consumption of most plant-source foods during pregnancy and early lactation by food security status. Increasing animal-source food intake among food insecure women remains as a critical challenge to improve maternal diet.

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Figures and Tables for Chapter 5

Table 5.1: Women's and household characteristics by household food security category (N=14,600)[1]

			Food insecurity						
	Food secure		Mild		Moderate		Severe		p-value
Women's variables									
GA at 1TM, wk	7332	11.0 ± 4.8	2929	11.0 ± 5.0	2232	11.1 ± 5.1	2068	11.3 ± 5.6	0.06
GA at 3TM, wk	7332	32.6 ± 2.0	2929	32.5 ± 2.1	2232	32.6 ± 2.5	2068	32.6 ± 2.7	0.91
Postpartum weeks at 3MP, wk	7344	12.9 ± 2.1	2936	13.1 ± 1.8	2241	13.2 ± 1.7	2077	13.3 ± 1.6	***
Age at 1TM, y	7346	22.8 ± 5.3	2936	22.4 ± 5.2	2241	22.4 ± 5.3	2077	24.4 ± 5.9	***
MUAC at 1TM, cm	7346	24.0 ± 2.4	2935	23.6 ± 2.2	2241	23.3 ± 2.1	2076	23.0 ± 1.9	***
Socio-economic variables									
Religion	7346		2936		2241		2077		
Muslim		91.5		93.3		90.9		90.3	**
Other		8.5		6.7		9.1		9.7	
Maternal education	7344		2932		2239		2077		***
No education		14.8		23.2		31.9		46.5	
Primary or higher		85.2		76.8		68.1		53.5	
Household size, n	7345	4.4 ± 2.2	2936	4.0 ± 1.8	2240	4.0 ± 1.7	2077	4.0 ± 1.5	***
Dependency ratio	7345	0.6 ± 0.4	2935	0.5 ± 0.4	2240	0.6 ± 0.5	2077	0.7 ± 0.5	***
Wealth index	7338	0.5 ± 1.0	2933	-0.1 ± 0.8	2241	-0.4 ± 0.7	2076	-0.7 ± 0.6	***

Abbreviation: GA, gestational age; 1TM, 1st trimester; 3TM, 3rd trimester; 3MP, 3 mo postpartum; BF, breastfeeding; MUAC, mid-upper arm circumference

1. Values are n, % or n, mean ± SD. Difference between sum of n and total N represent missing values.

2. P-value is the ANOVA test for continuous variables or Chi-square test for categorical variables. **<0.01, ***<0.001.

Table 5.2: Women's dietary diversity score by household food insecurity status[1]

	All	Food secure	Food insecurity			p-
			Mild	Moderate	Severe	
	(N=14,600)	(n=7,346)	(n=2,936)	(n=2,241)	(n=2,077)	value[2]
1st trimester (1TM)	5.9 ± 1.7	6.2 ± 1.7	5.8 ± 1.7	5.6 ± 1.6	5.3 ± 1.6	***
3rd trimester (3TM)	6.0 ± 1.8	6.3 ± 1.7	5.9 ± 1.7	5.6 ± 1.7	5.3 ± 1.7	***
Pregnancy average (PA)	5.9 ± 1.4	6.3 ± 1.4	5.9 ± 1.4	5.6 ± 1.3	5.3 ± 1.4	***
3 mo postpartum (3MP)	5.3 ± 1.7	5.6 ± 1.7	5.2 ± 1.7	5.0 ± 1.6	4.7 ± 1.6	***
Difference (1TM-3TM)[3]	0.1 ± 1.9	0.1 ± 1.9‡	0.1 ± 2.0‡	0.1 ± 2.0†	0.04 ± 1.9	0.13
Difference (3MP-PA)[3]	-0.7 ± 1.7	-0.7 ± 1.7‡	-0.7 ± 1.7‡	-0.7 ± 1.7‡	-0.6 ±1.8‡	0.24

Abbreviation: GA, gestational age; BF, breastfeeding;

1. Values are mean ± SD.
2. P-value for the ANOVA test on equal mean across HFI groups. * <0.05; ***<0.001
3. P-value for the pair-wise T-test on equal mean difference within each HFI group. † <0.01; ‡ <0.001

Figure 5.1: Women's dietary diversity score by household food security category and season (N=14,600, all p<0.001)

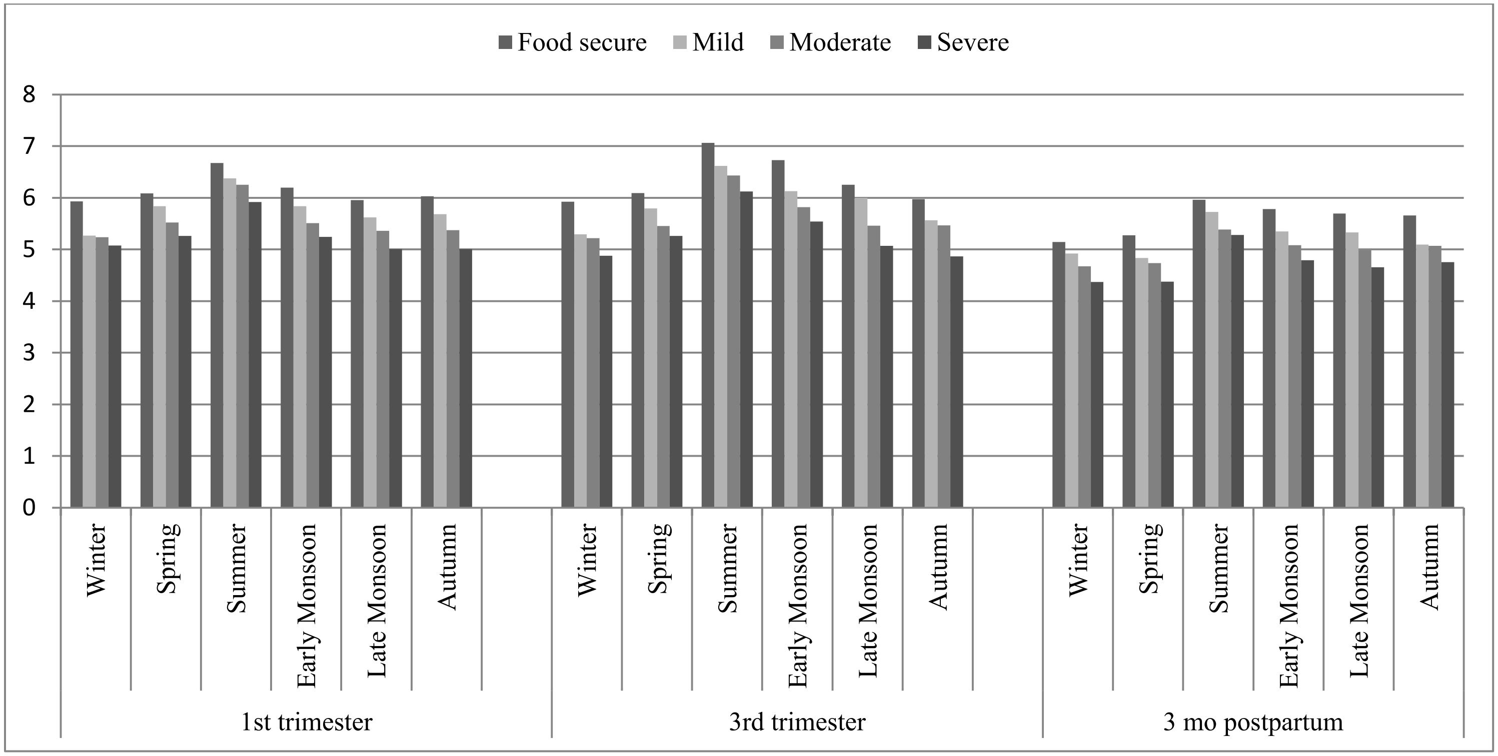
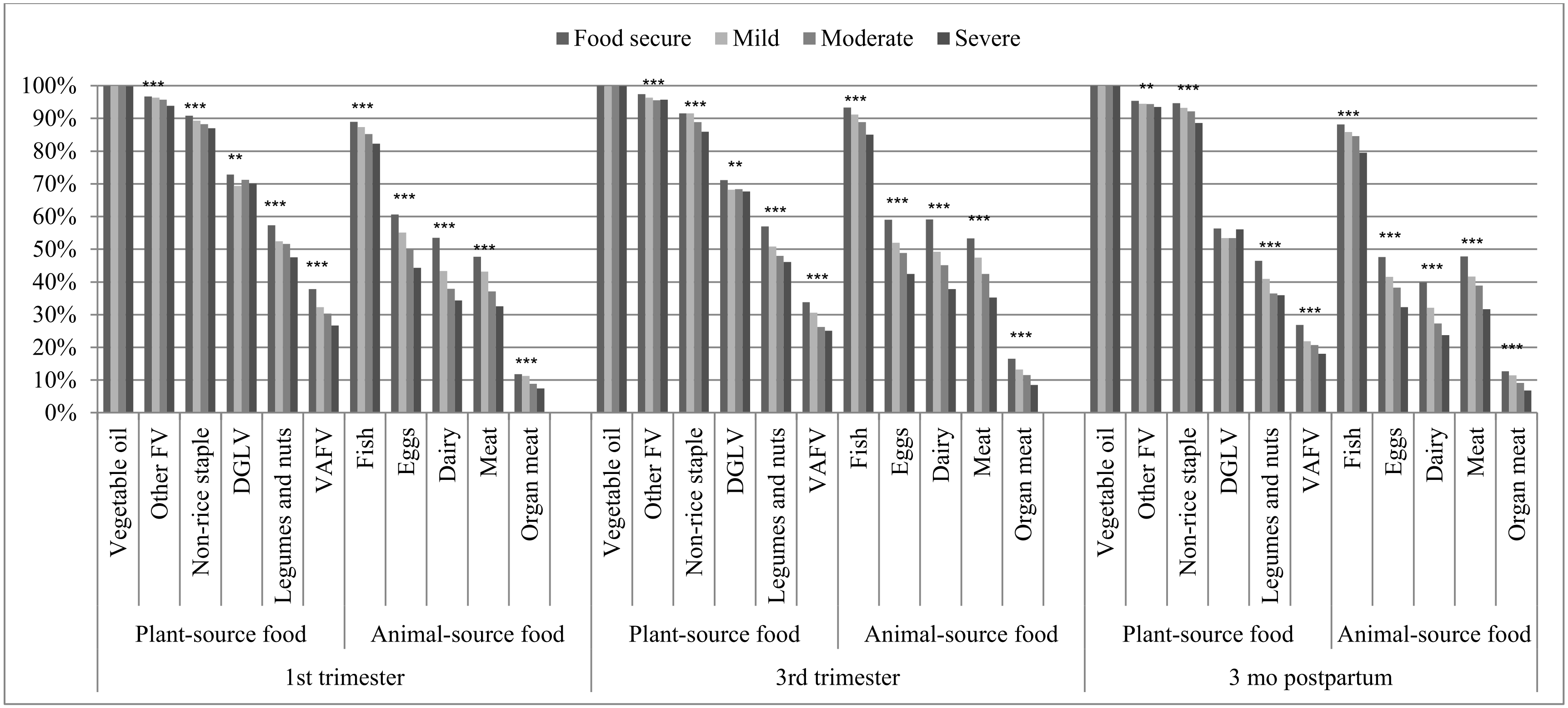


Figure 5.2: Proportion of women reported any consumption of food groups by household food insecurity category



Abbreviation: OR, odds ratio; DGLV, dark green leafy vegetables; VAFV, vitamin A-rich fruit and vegetables; Other FV, other fruit and vegetables. P-values: **<0.01; ***<0.001

Table 5.3: Crude odds ratio (95% CI) of women's food group consumption comparing food insecure groups with the food secure group (reference)

		Crude[1] OR (95%CI)					
		Household food insecurity					
	n	Mild		Moderate		Severe	
1st trimester (1MP)							
Vegetable oil	14600	1.20 (0.32, 4.43)		2.75 (0.35, 21.70)		0.64 (0.20, 2.07)	
Other FV	14600	0.90 (0.71, 1.14)		0.76 (0.60, 0.97)	*	0.51 (0.41, 0.64)	***
Non-rice staple	14600	0.85 (0.73, 0.97)	*	0.76 (0.65, 0.88)	***	0.67 (0.58, 0.78)	***
DGLV	14600	0.85 (0.77, 0.93)	***	0.93 (0.83, 1.03)		0.87 (0.79, 0.97)	*
Legumes and nuts	14600	0.82 (0.75, 0.89)	***	0.79 (0.72, 0.87)	***	0.67 (0.61, 0.74)	***
VAFV	14600	0.79 (0.72, 0.86)	***	0.71 (0.65, 0.79)	***	0.60 (0.54, 0.67)	***
Fish	14600	0.86 (0.75, 0.98)	*	0.72 (0.62, 0.82)	***	0.57 (0.50, 0.66)	***
Eggs	14600	0.80 (0.73, 0.87)	***	0.65 (0.59, 0.71)	***	0.52 (0.47, 0.57)	***
Dairy	14600	0.67 (0.61, 0.73)	***	0.53 (0.48, 0.59)	***	0.45 (0.41, 0.50)	***
Meat	14600	0.83 (0.76, 0.91)	***	0.65 (0.59, 0.71)	***	0.53 (0.48, 0.59)	***
Organ meat	14600	0.95 (0.83, 1.09)		0.72 (0.62, 0.85)	***	0.60 (0.50, 0.71)	***
3rd trimester (3TM)							
Vegetable oil	14600	0.30 (0.07, 1.34)		0.92 (0.10, 8.80)		0.85 (0.09, 8.16)	
Other FV	14600	0.70 (0.55, 0.89)	**	0.57 (0.44, 0.72)	***	0.60 (0.46, 0.77)	***
Non-rice staple	14600	1.00 (0.86, 1.17)		0.74 (0.63, 0.86)	***	0.56 (0.48, 0.65)	***
DGLV	14600	0.87 (0.79, 0.95)	**	0.88 (0.79, 0.97)	*	0.85 (0.77, 0.94)	**
Legumes and nuts	14600	0.78 (0.72, 0.85)	***	0.70 (0.63, 0.76)	***	0.65 (0.59, 0.71)	***
VAFV	14600	0.86 (0.79, 0.94)	**	0.69 (0.62, 0.77)	***	0.65 (0.59, 0.73)	***
Fish	14600	0.75 (0.64, 0.87)	***	0.57 (0.49, 0.67)	***	0.41 (0.35, 0.48)	***
Eggs	14600	0.75 (0.69, 0.82)	***	0.66 (0.60, 0.73)	***	0.51 (0.46, 0.56)	***
Dairy	14600	0.67 (0.61, 0.73)	***	0.57 (0.52, 0.63)	***	0.42 (0.38, 0.47)	***
Meat	14600	0.79 (0.73, 0.86)	***	0.65 (0.59, 0.71)	***	0.48 (0.43, 0.53)	***
Organ meat	14600	0.77 (0.68, 0.87)	***	0.66 (0.57, 0.76)	***	0.47 (0.40, 0.56)	***
3 mo postpartum (3MP)							
Vegetable oil	12359	0.60 (0.10, 3.59)		1.00 (1.00, 1.00)	-	0.85 (0.09, 8.16)	
Other FV	14600	0.84 (0.69, 1.01)		0.83 (0.67, 1.02)		0.70 (0.57, 0.86)	***
Non-rice staple	14600	0.79 (0.66, 0.94)	**	0.67 (0.55, 0.80)	***	0.44 (0.37, 0.53)	***
DGLV	14600	0.89 (0.82, 0.97)	**	0.89 (0.81, 0.98)	*	0.99 (0.90, 1.09)	
Legumes and nuts	14600	0.80 (0.73, 0.87)	***	0.66 (0.60, 0.73)	***	0.65 (0.59, 0.72)	***
VAFV	14600	0.76 (0.69, 0.84)	***	0.71 (0.63, 0.80)	***	0.60 (0.53, 0.68)	***
Fish	14600	0.82 (0.72, 0.93)	**	0.74 (0.65, 0.85)	***	0.52 (0.46, 0.60)	***
Eggs	14600	0.78 (0.72, 0.85)	***	0.68 (0.62, 0.75)	***	0.52 (0.47, 0.58)	***
Dairy	14600	0.71 (0.65, 0.78)	***	0.57 (0.51, 0.63)	***	0.47 (0.42, 0.53)	***
Meat	14600	0.78 (0.71, 0.85)	***	0.69 (0.63, 0.76)	***	0.51 (0.46, 0.56)	***
Organ meat	14600	0.89 (0.78, 1.02)		0.69 (0.59, 0.81)	***	0.51 (0.42, 0.61)	***

Abbreviation: OR, odds ratio; DGLV, dark green leafy vegetables; VAFV, vitamin A-rich fruit and vegetables; Other FV, other fruit and vegetables. P-values: *<0.05, **<0.01, ***<0.001.

1. Values are OR (95%CI) of each food group consumption comparing food insecure women with food secure women (reference group not shown)

Table 5.4: Adjusted odds ratio (95% CI) of women's food group consumption comparing food insecure groups with the food secure group (reference)

		Adjusted[1] OR (95%CI)		
		Household food insecurity		
	n	Mild	Moderate	Severe
1st trimester (1TM)				
Vegetable oil	11307	1.62 (0.43, 6.18)	4.20 (0.5, 34.96)	1.33 (0.35, 5.07)
Other FV	14575	1.17 (0.92, 1.48)	1.12 (0.86, 1.45)	0.91 (0.70, 1.17)
Non-rice staple	14575	0.91 (0.78, 1.06)	0.88 (0.74, 1.04)	0.90 (0.76, 1.07)
DGLV	14575	0.95 (0.86, 1.05)	1.09 (0.98, 1.23)	1.07 (0.95, 1.20)
Legumes and nuts	14575	1.08 (0.99, 1.19)	1.20 (1.08, 1.33) ***	1.20 (1.07, 1.34) **
VAFV	14575	0.97 (0.87, 1.07)	1.01 (0.90, 1.13)	0.99 (0.87, 1.12)
Fish	14575	0.97 (0.85, 1.11)	0.88 (0.76, 1.02)	0.76 (0.66, 0.89) ***
Eggs	14575	0.93 (0.85, 1.02)	0.86 (0.77, 0.95) **	0.79 (0.71, 0.88) ***
Dairy	14575	0.85 (0.78, 0.94) ***	0.78 (0.71, 0.87) ***	0.74 (0.66, 0.83) ***
Meat	14575	1.02 (0.93, 1.11)	0.89 (0.80, 0.99) *	0.84 (0.75, 0.94) **
Organ meat	14575	1.16 (1.01, 1.33) *	1.00 (0.84, 1.19)	0.99 (0.81, 1.20)
3rd trimester (3TM)				
Vegetable oil	9887	0.35 (0.07, 1.64)	1.23 (0.12, 13.08)	1.35 (0.12, 15.72)
Other FV	14575	1.00 (0.78, 1.28)	0.98 (0.75, 1.27)	1.26 (0.95, 1.68)
Non-rice staple	14575	1.13 (0.96, 1.33)	0.86 (0.73, 1.02)	0.66 (0.55, 0.79) ***
DGLV	14575	1.00 (0.91, 1.11)	1.06 (0.95, 1.19)	1.06 (0.94, 1.19)
Legumes and nuts	14575	1.01 (0.92, 1.11)	1.02 (0.92, 1.14)	1.12 (1.00, 1.26) *
VAFV	14575	1.04 (0.94, 1.16)	0.91 (0.81, 1.03)	0.97 (0.85, 1.11)
Fish	14575	0.95 (0.80, 1.11)	0.83 (0.70, 0.98) *	0.67 (0.56, 0.80) ***
Eggs	14575	0.92 (0.84, 1.01)	0.93 (0.84, 1.03)	0.80 (0.71, 0.89) ***
Dairy	14575	0.85 (0.78, 0.93) ***	0.83 (0.75, 0.93) ***	0.71 (0.64, 0.80) ***
Meat	14575	0.97 (0.88, 1.06)	0.91 (0.82, 1.01)	0.78 (0.69, 0.87) ***
Organ meat	14575	0.96 (0.84, 1.10)	0.97 (0.83, 1.13)	0.84 (0.70, 1.01)
3 mo postpartum (3MP)				
Vegetable oil	8763	0.97 (0.15, 6.22)	1.00 (1.00, 1.00) -	2.44 (0.21, 28.33)
Other FV	14573	1.07 (0.87, 1.30)	1.23 (0.98, 1.54)	1.16 (0.92, 1.45)
Non-rice staple	14573	0.92 (0.76, 1.11)	0.85 (0.69, 1.04)	0.60 (0.49, 0.74) ***
DGLV	14573	1.03 (0.94, 1.13)	1.06 (0.96, 1.18)	1.24 (1.11, 1.39) ***
Legumes and nuts	14573	1.05 (0.96, 1.16)	0.96 (0.86, 1.07)	1.02 (0.91, 1.15)
VAFV	14573	1.00 (0.89, 1.12)	1.05 (0.92, 1.20)	0.98 (0.84, 1.13)
Fish	14573	1.02 (0.90, 1.16)	1.04 (0.90, 1.20)	0.82 (0.71, 0.94) **
Eggs	14573	0.95 (0.87, 1.04)	0.94 (0.85, 1.05)	0.83 (0.74, 0.93) **
Dairy	14573	0.94 (0.86, 1.04)	0.86 (0.77, 0.96) **	0.78 (0.69, 0.88) ***
Meat	14573	0.95 (0.87, 1.04)	0.98 (0.88, 1.09)	0.81 (0.72, 0.91) ***
Organ meat	14573	1.10 (0.96, 1.27)	0.98 (0.83, 1.17)	0.85 (0.69, 1.04)

Abbreviation: OR, odds ratio; DGLV, dark green leafy vegetables; VAFV, vitamin A-rich fruit and vegetables; Other FV, other fruit and vegetables. P-values: *<0.05, **<0.01, ***<0.001.

1. Values are OR (95%CI) of each food group consumption comparing food insecure women with food secure women (reference group not shown), adjusting for women's age, postpartum week at assessment (for 3 mo postpartum assessment only), women's MUAC at 1st trimester, women's education, women's religion, FFQ assessment season, household size, dependency ratio, and wealth index.

CHAPTER 6: Household Food Insecurity and Changes of Maternal Nutritional Status during Pregnancy and Early Postpartum Period in Rural Bangladesh

Abstract

Good nutrition during pregnancy and lactation helps to assure a healthy pregnancy outcome and adequate infant growth. Food insecurity may limit access to nutritional foods and affect nutritional status during pregnancy and lactation. Yet, the dynamic relationship between household food insecurity (HFI) and maternal nutrition during these demanding periods is poorly understood in developing countries. Using data from a large cluster-randomized antenatal supplementation trial in rural Bangladesh, we studied the relationship between HFI, assessed by a 9-item behavior-based scale at 6 months postpartum, and prospectively measured maternal weight and mid-upper arm circumference (MUAC), from the 1st trimester to 3 months postpartum using bivariate and multivariate linear regression models. HFI was associated with a shorter maternal stature, lower weight and smaller MUAC, and higher risk of undernutriton in the 1st trimester. After controlling for season, maternal and socioeconomic factors, seasonality, but not HFI, was strongly associated with changes in maternal weight and MUAC in pregnancy and lactation. Per one unit increase in body mass index in 1st trimester, women gained 370 g less in weight and 0.17 cm less in MUAC from 1st to 3rd trimester. For every one additional kilogram gained from the 1st trimester to the 3rd trimester in pregnancy, women lost 120-130 g more in weight and 0.04-0.06 cm in MUAC in lactation from 1 to 3 mo postpartum. HFI assessed in rural Bangladeshi setting reflected chronic food insecurity condition, which exerted influence on maternal prepregnancy nutritional status and sequentially on the maternal nutritional status in the pregnancy-

lactation cycle. While sustainable food security enhancement is the goal, short-term food supplement in lean seasons for pregnant and lactating women would also be important to improve maternal nutrition and feto-infant growth.

Introduction

Pregnancy and lactation are two critical physiological periods for maternal and child health outcomes (1-3). Increased nutrition requirement may place pregnant or lactating women at higher risk of energy (4) and/or micronutrient deficiencies (5-8). Household food insecurity (HFI) could worsen maternal nutrition in the two critical periods because it is harder to fill the increased nutrition demand with poorer food quality and food quantity. In the previous chapter, we identified antenatal and early postnatal dietary quality was lower in a dose-response way by the intensity of HFI in rural Bangladesh (Chapter 4). Whether the HFI associated deficit in dietary intake also reflects in maternal nutritional status remains unknown. Besides a few studies exploring the relationship between HFI and excessive gestational weight gain in the US (9, 10), no study has been identified to compare gestational and postpartum nutritional status by HFI status in developing countries. In this study, we hypothesize that HFI is associated with less weight and MUAC gain in pregnnacy and greater weight and MUAC loss in lactation.

Methods

Study area and population

A large, cluster-randomized control trial was conducted in the Gaibandha District in rural northwestern Bangladesh to compare a 15 multiple micronutrient antenatal supplementation versus folic acid and iron alone on maternal and infant survival and health. Details about the study area (11) and this trail (12) was described somewhere else. Briefly, newly pregnant women aged 13-45 years were consented to join the trial after amenorrhea was detected by menstruation surveillance and pregnancy was confirmed by a urine test. Participating women were then assigned to one of the supplementation arms by cluster and started taking daily tablet usually a week after recruitment till 3 month postpartum. At recruitment usually within the first trimester (1TM), trained female interviewer visited the woman's home and collected information about age, previous pregnancy history, dietary frequency, anthropometry and socioeconomic status using structured questionnaire. Follow up visits were scheduled at 3rd trimester (3TM), 1 month (1MP) and 3 month (3MP) postpartum to assess dietary frequency, and history of listed heavy physical activities, and breastfeeding behaviors after the baby was born.

Women eligible for this current study have been enrolled in the trial within their first trimester (gestational age or GA≤12 weeks). To study the relationship between HFI and maternal nutritional status among those with 'healthy' pregnancy, only women with term singleton live births (gestational age at birth>37 weeks) were included (N=8,848). Exclusion criteria included: 1) GA greater than 40 weeks at 3TM follow up (n=63); 2) The 1MP visit took place beyond the 8th week postpartum (n=1,034) or the 3MP visit beyond the 16th week postpartum (n=370); 3) subjects with reported gestational edema (swelling of hands or face, n=42); or 4) missing response in any item of the household food insecurity questionnaire (n=1). As the results the set of inclusion and exclusion criteria, a final sample of 7,338 women are included for analysis.

Controlled variables

Women's last menstrual period (LMP) was obtained from the 5-week pregnancy surveillance visits. GA in weeks at each visit was calculated as the interval between the date of LMP and date of 1TM or 3TM visit during pregnancy. Date of birth was acquired from a community-based birth notification system. Postpartum weeks at 1MP or 3MP visit were calculated as the interval between date of interview and the date of birth. The GA length in weeks and postpartum week length were calculated as the interval between two visits during pregnancy and during lactation, respectively. At recruitment, participating women were asked about their lifetime pregnancy, including date and outcome of each previous pregnancy. The interpregnancy interval between the current pregnancy and the last one was calculated as the difference between the LMP date of the current pregnancy and the outcome date of the most recent pregnancy.

Women's characteristics

Women's usual diet was assessed by a 7-day food frequency questionnaire (FFQ) at 1TM, 3TM and 3MP visits. The same 32 common food items were included in the FFQ at each assessment. Women's dietary diversity score (WDDS) was calculated as the total number of 10 food groups according to the FAO classifications (13) consumed in the past week. Because there is no significant interpersonal variation in WDDSs between the 1TM and 3TM assessments (Chapter 5), we calculated the averaged WDDSs to represent usual dietary quality in pregnancy. A brief work history during the past 7 days was also asked at 3TM and 3MP. Heavy physical activities were selected based on the rural Bangladeshi culture, including 1) carried heavy objects (≥20 kg); 2) husked, ground or pounded grain; 3) gathered and/or cut folder; 4) chopped or cut fire wood, and 5) Walked more than one hour. Each woman was labeled as any versus none of the work done at 3TM and 3MP. Whether or not woman was still breastfeeding their baby was assess at 3MP. The intensity of breastfeeding was assessed by asking the feeding frequency during the past day and whether the infant get sufficient breast milk as it wanted.

Anthropometry measurement

Women's height was measured twice at 1TM and 3MP using a portable stadiometer to the nearest 0.1 cm. Women's weight and mid-upper arm circumference (MUAC) were measured twice during pregnancy at 1TM and 3TM and twice during lactation at 1MP and 3MP. Women were weighted in light cloth on SECA digital scales (UNICEF) to the nearest 100 g and their MUAC was taken using an insertion tape to the nearest 0.1 cm. Triplicate measurements of height and MUAC were taken at every assessment and the median of the three was used as the representative value. Maternal body mass index (BMI) was calculated as weight/ height^2 (kg/m^2) and low BMI was defined as a BMI value less than 18.5 kg/m^2.

Socioeconomic status assessment

At recruitment, trained female interviewers revisited women at home shortly after consent was acquired to conduct the socioeconomic status assessment. By applying a standard questionnaire, the interviewer asked about women's education level, her religion, number of people living in the household, ownership of agricultural resources including land and livestock, ownership of durable assets, and dwelling characteristics, such as number of living rooms, type of toilet facility, and electricity availability. Household construction of the ground floor, roof and kitchen was assessed by the interviewer based on direct observation. A wealth index using selective socioeconomic variables was created according to a previous published methodology (14).

Household food insecurity (HFI)

The Food Access Survey Tool (FAST) was used to assess the household food security status. FAST is a 9-item Likert scale that has been developed and validated by the Food and Nutrition Technical Assistance Project in Bangladesh (15). At 6 mo postpartum (6MP), women were asked to respond to the FAST by recalling the frequency of their food insecurity experiences in the past 6 months, including concerns and anxiety over food acquisition, reduction in food quality and/or food quantity, and socially acceptable strategies used to cope with HFI, such us taking out loan from shops, and borrowing money to buy food. Responses for frequencies are: 0=never (0 time/ 6mo);1=rarely (1-3 times /6 mo); 2=sometimes (4-6 times /6 mo); 3=often (a few times each week) or 4=mostly (most days per week). Question about “square meals” is reversely coded because it is the only question about sufficiency instead of deprivation. The sum of the 9 frequency responses is used as a HFI index (HFII) with higher score representing severe food insecurity status. Households with zero value HFII are classified as food secure and the rest of the households were categorized into mild, moderate and severe groups on the tertile cutoffs of all non-zero HFIIs. Six Bangladeshi seasons starting from mid-December for every two months has been defined based on the date of household food insecurity at 6 month postpartum (16).

Statistical analysis

Controlled variables, women's and household characteristics, and maternal nutritional status were compared by HFI groups. The significance of differences in distribution by HFI groups was tested by ANOVA for continuous variables or by Chi-square test for categorical variables.

Multivariate linear regression methods were applied to model the absolute changes in weight and MUAC during pregnancy and during lactation in unadjusted models (model 1), adjusting for maternal factors only (model 2), and adjusting both maternal and household factors (model 3). In pregnancy, age, parity, BMI at enrollment, GA length between two visits, and heavy physical activities were recognized as maternal factors related to nutritional status change; in lactation, duration between two postpartum visits in replacement of GA length, and additionally GA weight gain from 1TM to 3TM, breastfeeding frequency and sufficiency were included as first level adjustment for primiparous women. Two additional variables of proceeding pregnancy outcome and interval were included for multiparous women. Predictors for household food availability and allocation were seasonality, religion, household size, maternal education and wealth index. Food secure group was treated as the reference in the comparisons of maternal nutritional status using multivariate linear regression models. The significance level of p-value was set at 0.05. All analyses were performed on STATA/SE 13.1 (StataCorp, College Station, Texas).

Results

Among the 7,338 women, 3,642 (49.6%) were categorized as food secure and 1,452 (19.8%), 1,173 (16.0%) and 1,071 (14.6%) are under the mild, moderate and severe HFI groups, respectively. The distribution of controlled variables and women's and household characteristics were presented in **Table 6.1**. The gestational (GA) or postpartum week in which assessments were conducted did not differ by HFI status, except for the GA week at 3TM visit ($p<0.01$), which appears slightly earlier among the food insecure households. The duration between two consecutive assessments was equal across HFI groups, about 23.5 wk in pregnancy ($p=0.10$) and 8.6 wk in lactation ($p=0.22$). The average age of participating women were around 23 years for food secure and mildly and moderately insecure women but was 24.7 years among the severely insecure women ($p<0.001$). Progressively with the severity of HFI, women had more parity ($p<0.001$). Among those women who had at least one past pregnancy experience, 85-86% previous pregnancy ended up with a live birth regardless of HFI status ($p=0.83$). Most of them managed a birth space greater than 18 mo from the proceeding pregnancy to the current pregnancy (>90%); however, HFI was associated with increased likelihood of birth space <18 mo ($p<0.01$). Food insecure women had less antenatal and postnatal dietary diversity scores ($p<0.001$). More proportion of food insecure women reported conducting heavy physical work in pregnancy ($p<0.001$) but the proportion during lactation was lower and indifferent across HFI groups ($p=0.23$). Breastfeeding at 3MP was universal (>99%) and but breastfeeding was less intense with worsened HFI, in terms of frequency ($p<0.05$) and sufficiency ($p<0.001$). Women were living in a predominant Muslim culture although the proportion of Muslim religion was observed the highest of 93.0% among mild HFI group and lowest of 89.3% among severely HFI ($p<0.01$). The proportion of women reported having primary or higher education significantly went down from 82.9% in food secure group to 76.7%, 65.4% and 53.2% in the mild, moderate and severely HFI group, respectively. About four people including the woman living under the same household yet the distribution was not equal due to the slightly bigger household size among food secure families ($p<0.001$). Wealth index was highly correlated with HFI category ($p<0.001$). By HFI groups, the season in which the HFI assessment was conducted showed some heterogeneity in distribution.

Table 6.2 compared the nutritional status of women and the birth size of their babies at delivery by HFI category. At 1TM when women were first measured, maternal height, weight, MUAC, and BMI were progressively decrease with the increasing severity in HFI (all $p<0.001$). About 40% of the women in food secure group were undernourished at 1TM and the prevalence increased to 41.7, 45.4, and 48.7% in the mild, moderate and severe HFI group, respectively. In pregnancy, women gained ~5.6 kg from 1TM to 3TM and lost 0.2 cm in MUAC. During lactation, the average absolute weight loss was 150g at a rate of 20g/wk, which did not differ by HFI status. An average 0.3 cm gain in MUAC was observed and the mean rate of MUAC gain displayed a linear trend: at highest rate of ~37 mm/wk in food secure and mildly insecure group, then decrease to 36.1 and 34.7 mm/wk in other two groups. Birth weight and birth length were linearly smaller by food security status (both $p<0.01$). Proportion of low birth weight (<2.5kg) among the term babies was 32.9% in the food secure group and increased with progressive food insecurity stages, at 36.4% 37.9% and 38.7% for mild, moderate and severe HFI, respectively.

Figure 6.1 and **Figure 6.2** presented the trajectory of women's weight and MUAC from early pregnancy to early lactation, respectively. The pattern of weight change from 1TM to 3MP was similar for women with different initial weight at the onset of pregnancy. Women who had greater MUAC at 1TM lost MUAC from 1TM to 3TM and gained slightly in MUAC in the first 3 mo after delivery. Women who entered pregnancy with small MUAC, however, maintained their MUAC low around 20 cm with no obvious change in MUAC observed during the course of follow-up. Results from multilevel models also suggested that more than 90% of overall variance in nutritional status was attributable to the variance in weight or MUAC between women at 1st trimester (**Appendix 6.1**). Data did not support significant interaction effect of HFI status on weight or MUAC change during pregnancy or lactation (Appendix 6.1).

The results from multivariate linear regression models were presented in **Table 6.3-6.5**. Weight and MUAC change in pregnancy was summarized in **Table 6.3A and 6.3B** separately and the corresponding results in lactation were presented by women's parity status (**Table 6.4** for primiparous women; **Table 6.5** for multiparous women) and by outcome of interest (A: weight change; B: MUAC change). HFI was not associated with weight or MUAC change during pregnancy or lactation, with the only exception observed in unadjusted MUAC change in pregnancy (table 6.3B). Per one unit increase in BMI at 1TM, women gain ~370 g less in weight and 0.17 cm less in MUAC during pregnancy. For both primiparous and multiparous women's postpartum weight and MUAC changes are negatively associated with gestational weight gain. For every one more kilogram gained in pregnancy from 1TM to 3TM, women lost ~120-130 g more in weight and lost 0.04-0.06 cm more in MUAC from 1MP to 3MP. After adjusting for maternal factors and other socioeconomic status, seasonality was associated with substantial absolute gain/loss in maternal weight and MUAC during both pregnancy and lactation. Bigger household size was associated with less gestational weight gain and more postpartum weight loss by about 40 g per every one more family number increased; per one unit increase in wealth index, pregnancy weight gain increase by 224 g and MUAC increase by 0.07 cm, accounting for other maternal and household factors. Among primiparous women, wealth index was only marginally (p=0.047) associated with increased postpartum weight loss by 92.2 g per each unit of wealth index increased. Maternal education and religion were not associated with nutritional status change in pregnancy or lactation.

Discussion

In rural Bangladesh, where more than 60-70% of calorie intake is from the staple rice (17-19), energy availability is heavily dependent on the agricultural pattern of three major rice crops: *aman*, *aus* and *boro*. *Aman* and *aus* are the rainfed rice, which sowed in the humid season prior to the rainy monsoon season from mid-March to mid-August. *Boro* is the irrigated rice, which is sowed in the dry season from mid-November to mid-January. Harvest months for *aman*, *aus* and *boro* are November to mid-December, July to mid-August, and mid-April to May, respectively (Chapter 2 Figure 2.3). Food is more available during harvest seasons and is particularly scarce in the preharvest period of rice, lasting from mid-September to November prior to aman harvest, known as *Monga*, and from mid-March to mid-April prior to boro harvest, known as *little Monga* (20) (Chapter 2 Figure 2.3, **Figure 6.3**). In rural Bangladesh, consumption of almost all food was found lowest in the lean season (21, 22). Women's ponderal status, specifically weight (22-24) and MUAC (22, 23), fluctuate accordingly to seasonal variation of food availability, reaching to the lowest point in the lean season and climbing back gradually in the aman harvest season.

We identified strong association between season, not household food insecurity (HFI), with the changes in maternal size during pregnancy and lactation. Holding other maternal and household factors constant, we found ~960-1200 g less weight gain and among women who were visited in spring, summer or early monsoon at 6 mo postpartum (6MP) than women who were visited in winter at 6MP. Using figure 6.3 as a tool to track women's seasonal exposure during pregnancy, those who had less gestational weight gain compared to the winter reference group had some part of their 2nd (2TM) and 3rd trimester (3TM) in mid-September to November when *Monga* existed. The length and timing of *Monga* exposure correlated with the magnitude of weight deficit: a 960-970 g less weight gain was seen in the spring group with ~1 month *Monga* exposure in 3TM; in the early monsoon group with a mixture of 2.5 mo *Monga* and ~1 mo harvest season in 2TM and 3TM; the deficit was 300 g more of 1200 g for the summer group, whose 3TM was entirely in the mid-September to November window. There was no significant difference comparing the late monsoon group with the reference, probability because less weight gain from 2TM in *Monga* was caught up in harvest season in 3TM. The women in the autumn group who had *little Monga* covered in their 3TM, managed to gain 630 g more comparing with the winter reference group. The explanation was unclear. The gestational MUAC change followed the same seasonal pattern. In the spring, summer and early monsoon group, women were losing MUAC and in other season groups women were able maintain or gain in MUAC from the 1 mo (1MP) to 3 mo postpartum (**Appendix 6.2**).

The seasonal pattern in gestational weight gain and MUAC change was consistent with previous observations in poor rural settings. For example, Chowdhury et al (23) identified a difference in gestational weight gain of 1.2 kg and faster deterioration in MUAC comparing Bangladeshi women whose 2TM and 3TM was in lean season with women whose 1TM was in lean season. Seasonal variation in pregnancy weight gain is likely a consequence of fluctuation in both dietary intake and activity level in relation to season (25). Prenatal dietary energy supplementation had the greatest impact on gestational weight gain (26) and on birth size (26, 27) if given during hungry season, proving the negative energy balance did existed in food insufficient seasons. In our study, women on average gained a ~5.6 kg from 1TM to 3TM, ranging from 4.9 kg in the summer group and 6.9 kg in the autumn group, not differ by HFI status (**Appendix 6.2**). Not surprisingly, a similar seasonal pattern was observed in birth weight, given pregnancy weight gain was highly correlated with birth weight in developing countries (28). However, the seasonal pattern in birth weight was more profound among the severer HFI groups (**Appendix 6.3**), indicating stronger influence of gestational weight gain on birth weight among food insecure mothers who were shorter and more chronically undernourished (28, 29).

The seasonal variation in postpartum weight and MUAC were also visible (**Appendix 6.4**), which was unlikely explained by the food availability calendar alone (figure 6.3). In the previous chapter (Chapter 5), we found significant reduction in dietary diversity after women gave birth. We argued the common food restriction practice in lactation (30-32) may play an important role and may limit the influence of seasonal food availability on maternal nutrition. On the other hand, crop cultivation calendar (Chapter 2, figure 2.3) predicting women's activity level may be the major driver of the observed seasonal fluctuation in nutritional status. After accounting for maternal and household characteristics, we observed significantly positive difference in postnatal weight loss compared with women in the reference winter season group, whose first three postpartum months fell into monsoon season for sowing the Aman rice. Substantial postpartum weight loss in rainy season was previously observed among Bangladeshi women (33), probably due to their increased energy output in agricultural activities that was not fully captured by a one-week history of heavy physical activity. Postpartum women who were not benefit from the harvest season and whose 1MP-3MP window covered the April-May months (late monsoon group) was the only group had significant less MUAC gain compare with the reference season group. This time is the harvest season for Boro rice and wheat, during which women instead of men are demanded for post-harvest works.

HFI as assessed by FAST was likely measuring chronic rather than transit seasonal food insecurity status given its relatively long recall period of 6 month covering several seasons. Previously, we identified a consistent decreasing trend in maternal dietary quality from gestation to early lactation by HFI status measured at 6 mo postpartum (Chapter 5). It indicated though food security varies from season to season, the relative rank of chronic food insecurity stayed the same across households over lean and harvest season (**Appendix 6.5**). Under chronic food insecurity, energy adaptations in pregnancy, such as reduction in basal metabolic rate (28, 34) and smaller maternal fat deposition (34, 35), may occur to preserve energy for conceptus growth. With marginal energy intake and small gestational weight gain (25, 35), poorly nourished women were able to give birth to infant with acceptable weight (27, 36, 37). We did observe a decreasing trend in birth weight at term with progressive HFI. A recent study from the same study area (38) found the timing of fetal growth restriction, reflected by the percent of small-for-gestational age at birth, was not before 32 weeks but around 32-34 weeks of gestation and onwards. Our assessment window (9 -32 GA week) missed the final weeks of gestation, during which fetus weight growth reached to the peak velocity (39).

The null effect between HFI and postpartum weight loss was unexpected. Because of the lack of energy-sparing mechanism (40, 41) and small amount of fat storage from pregnancy (28, 35), the additional energy requirement to be filled from dietary intake was unlikely fulfilled under food insecurity circumferences. With HFI worsens, less proportion of women fed her child with sufficient milk, which could gradually decrease milk production (40) and save energy from milk synthesis. We found in our analyses that higher early pregnancy BMI predicts lower gestational weight gain, which in turn predicted less postnatal weight loss. The continuum change across physiological periods was also seen in MUAC change and was consistent with findings from previous studies (28, 42). As we found in this paper, the most variance in weight and MUAC change were attributed to the variance between women observed in the initial assessment. The evidences indicated that under static food security/insecurity status, the dynamics in maternal nutritional status during pregnancy and lactation was mainly a function of their nutritional status in early pregnancy.

Maternal factors, such as age, parity, BMI and physical activity, have shown predictive effect of gestational weight and MUAC change, which have been consistently reported in with the literature (37, 43). Among the socioeconomic factors examined, larger household size was an independent predictor, which was negatively associated with gestational weight gain and positively associated with postpartum weight loss. Intra-household food allocation might be less in favor of women in Bangladesh in the case of bigger families, because women received the last and smallest food shares during mealtimes under rural Bangladeshi culture (44-46). Also, maternal energy expenditure used in cooking and house chore to take care of the family may increase with the household size. Wealth index only showed strong independent impact on weight and MUAC change during pregnancy. Marginally significant or insignificant associations between wealth index and changes in maternal nutritional status were found among primiparous or multiparous women in lactation, respectively. Compare with the pregnancy period, maternal characteristics and household factors in lactation period were less significant, indicating those factors, including wealth index, may already exert their impact on nutritional status change through the pregnancy period. It supports treating pregnancy-lactation cycle as continuous process as previously discussed.

This study had limitations. HFI was measured only once at 6 month postpartum. The temporal relationship between HFI and maternal nutrition was based on an assumption of a static and chronic HFI over a ~1.5 year period from early pregnancy to 6 month postpartum. In Chapter 4, we found half of the households responded to a subset of FAST with exact same answers over a 1.2 year duration between two assessments and there was no evidence of substantial change in underlying socio-economic status, which predicted long-term HFI. Together by adjusting for season at 6MP in which FAST was assessed, we were able to compare chronic HFI status adjusting for seasonal variation in food insufficiency. We did not have energy intake assessed in our study. Previously we have found the food quality as well as frequency of food group consumption decreased with progressive HFI in pregnancy and lactation. Whether energy intake decreased with poorer food security was unknown. Physical activity as well as breastfeeding behavior, important components in energy expenditure, was only crudely measured. However, given the prospective design of the study and large sample size, the aforementioned limitations did not likely rule out the major findings from this research.

Conclusion

The absolute change in maternal nutritional status in gestation and early lactation is not different by household food insecurity. Food insecurity in rural Bangladesh, assessed by a behavior-based scale, chronically impacts on maternal prepregnancy nutritional status, which determines maternal ponderal status in the pregnancy-lactation cycle. Given the fact that maternal gestational and postpartum weight and MUAC are sensitive to seasonal food availabilities, food supplement and aid in lean seasons are promising to improve maternal and fetal nutrition, yet sustainable strategies to improve chronic household food security should be the long-term goal.

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Figures and Tables for Chapter 6

Table 6.1: Women's and household characteristics by household food security category[1]

	Food secure		Food insecurity: Mild		Food insecurity: Moderate		Food insecurity: Severe		p-value[2]
Controlled variables									
GA at 1TM, wk	3642	8.8 ± 1.6	1452	8.7 ± 1.6	1173	8.8 ± 1.6	1071	8.8 ± 1.6	0.33
GA at 3TM, wk	3642	32.4 ± 1.2	1452	32.3 ± 1.2	1173	32.3 ± 1.2	1071	32.3 ± 1.1	**
GA length, wk	3602	23.6 ± 1.9	1437	23.6 ± 1.9	1165	23.5 ± 1.9	1062	23.4 ± 1.9	0.10
Postpartum weeks at 1MP, wk	3642	4.9 ± 0.7	1452	4.9 ± 0.7	1173	4.9 ± 0.7	1071	4.8 ± 0.7	0.32
Postpartum weeks at 3MP, wk	3642	13.4 ± 0.7	1452	13.4 ± 0.7	1173	13.5 ± 0.7	1071	13.4 ± 0.7	0.36
Postpartum week length, wk	3602	8.6 ± 1.0	1437	8.6 ± 0.9	1165	8.6 ± 0.9	1062	8.6 ± 0.9	0.22
Maternal characteristics									
Age, y	3642	23.3 ± 5.2	1452	22.8 ± 5.2	1173	22.8 ± 5.2	1071	24.7 ± 5.8	***
Parity	3642		1451		1172		1071		***
0		31.6		32.3		33.6		19.3	
1		40.5		38.9		32.1		30.0	
≥2		27.9		28.7		34.3		50.7	
Proceeding pregnancy outcome, %	2585		1017		804		888		0.83
Live birth		86.2		85.7		86.8		85.4	
Other (MR/MC/SB)		13.8		14.3		13.2		14.6	
Proceeding interpregnancy interval, %	2510		992		769		852		**
≥18 mo		94.0		92.6		90.9		91.0	
<18 mo		6.0		7.4		9.1		9.0	
WDDS during pregnancy, n	3474	6.2 ± 1.4	1397	5.8 ± 1.4	1136	5.6 ± 1.4	1030	5.2 ± 1.4	***
WDDS during lactation, n	3606	5.5 ± 1.7	1434	5.2 ± 1.7	1157	5.0 ± 1.6	1058	4.7 ± 1.6	***
Heavy physical activity in 3TM, %	3613	24.2	1442	24.9	1169	28.7	1066	31.3	***
Heavy physical activity in 3PM, %	3639	22.6	1449	22.5	1169	25.0	1070	24.6	0.23
BF Frequency, times/day	3,639		1,450		1,169		1,070		*
Not BF		0.5		0.2		0.4		0.7	
1-10		7.1		8.2		7.3		9.2	
11-20		72.8		73.9		75.2		74.3	
≥21		19.6		17.7		17.1		15.9	
BF Sufficiency, %	3,617	88.3	1,447	86.3	1,163	85.6	1,061	80.4	***

(Table 6.1 cont'd)

	Food secure		Food insecurity						p-value[2]
			Mild		Moderate		Severe		
Socio-economic status									
Season of HFI assessment (6MP), %	3642		1452		1173		1071		***
Winter		14.8		14.7		14.2		15.2	
Spring		16.4		16.9		20.0		16.7	
Summer		19.6		21.8		20.5		20.5	
Early Monsoon		21.0		18.1		15.1		14.8	
Late Monsoon		17.2		15.8		16.3		15.0	
Autumn		11.0		12.5		13.8		17.7	
Women's religion, %	3642		1451		1172		1071		**
Muslim		91.2		93.0		91.8		89.3	
Other		8.8		7.0		8.2		10.7	
Women's education, %	3641		1449		1171		1071		***
No education		17.1		23.3		34.6		46.8	
Primary or higher		82.9		76.7		65.4		53.2	
Household size, n	3641	4.3 ± 2.1	1451	3.9 ± 1.7	1171	3.9 ± 1.7	1071	4.0 ± 1.4	***
Wealth index tertile, %	3641		1451		1172		1071		***
Low		17.5		35.4		50.6		67.0	
Medium		35.5		40.7		37.0		26.1	
High		47.0		24.0		12.4		6.9	

Abbreviation: 1T, 1st trimester; 3T, 3rd trimester; 1, 3, or 6MP, 1, 3 or 6 mo postpartum; GA, gestational age; WDDS, women's dietary diversity score; BF, breastfeeding; MR/MC/SB, induced abortion (menstrual regulation), miscarriage, stillbirth; HFI, household food insecurity.

1. Values are n and mean ± SD or %.

2. P-value is the ANOVA test for continuous variables or Chi-square test for categorical variables. **<0.01, ***<0.001.

Table 6.2: Nutritional status of women and newborn by household food insecurity status[1]

	Food secure		Food insecurity						p-value[2]
			Mild		Moderate		Severe		
Pregnancy									
Height	3636	150.4 ± 5.1	1447	149.7 ± 5.0	1172	149.5 ± 5.0	1066	148.9 ± 5.3	***
Weight									
1TM, kg	3635	43.9 ± 6.6	1446	43.1 ± 6.0	1170	42.4 ± 5.9	1069	41.5 ± 5.4	***
3TM, kg	3612	49.5 ± 6.6	1439	48.7 ± 5.9	1169	48.1 ± 5.8	1066	47.3 ± 5.5	***
Δ Weight (3TM-1TM), g	3598	5595.0 ± 2658.0	1432	5619.8 ± 2625.6	1162	5695.7 ± 2548.6	1062	5739.7 ± 2589.8	0.36
Weight gain rate, g/wk	3598	238.5 ± 114.9	1432	239.7 ± 113.1	1162	243.3 ± 109.4	1062	247.3 ± 114.1	0.13
MUAC									
1TM, cm	3637	23.9 ± 2.4	1448	23.7 ± 2.2	1172	23.4 ± 2.1	1069	23.0 ± 2.0	***
3TM, cm	3611	23.7 ± 2.2	1441	23.5 ± 2.1	1169	23.2 ± 2.0	1066	22.9 ± 1.8	***
Δ MUAC (3TM-1TM), cm	3599	-0.2 ± 1.2	1434	-0.2 ± 1.2	1164	-0.2 ± 1.1	1062	-0.1 ± 1.1	**
MUAC change rate, mm/wk	3599	-9.8 ± 49.9	1434	-7.9 ± 49.3	1164	-6.3 ± 46.7	1062	-3.4 ± 47.9	**
BMI, kg/m^2									
1TM	3600	19.4 ± 2.5	1433	19.2 ± 2.3	1163	18.9 ± 2.2	1059	18.7 ± 2.1	***
3TM	3599	21.9 ± 2.4	1433	21.7 ± 2.1	1164	21.5 ± 2.1	1059	21.3 ± 2.0	***
Low BMI (<18.5 kg/m^2), %									
1TM	3600	40.2	1433	41.7	1163	45.4	1059	48.7	***

(Table 6.2 cont'd)

	Food secure		Food insecurity Mild		Moderate		Severe		p-value[2]
Lactation									
Height	3633	150.1 ± 5.1	1447	149.4 ± 5.1	1165	149.2 ± 5.1	1069	148.6 ± 5.3	***
Weight									***
1MP, kg	3630	45.0 ± 6.3	1445	44.1 ± 5.7	1165	43.5 ± 5.5	1069	42.8 ± 5.3	***
3MP, kg	3632	44.8 ± 6.4	1448	43.9 ± 5.8	1165	43.4 ± 5.6	1069	42.6 ± 5.3	***
Δ Weight (3MP-1MP), g	3586	-188.8 ± 1685.1	1431	-126.4 ± 1631.7	1153	-111.4 ± 1585.1	1060	-139.7 ± 1622.6	0.42
Weight change rate, g/wk	3586	-22.2 ± 196.4	1431	-15.4 ± 190.8	1153	-13.8 ± 190.1	1060	-17.9 ± 190.5	0.51
MUAC									
1MP, cm	3634	23.4 ± 2.2	1447	23.1 ± 2.1	1170	22.9 ± 2.0	1069	22.7 ± 1.9	***
3MP, cm	3631	23.7 ± 2.2	1449	23.5 ± 2.1	1166	23.2 ± 2.0	1069	23.0 ± 1.8	***
Δ MUAC (3MP-1MP), cm	3590	0.3 ± 0.7	1433	0.3 ± 0.8	1160	0.3 ± 0.7	1060	0.3 ± 0.8	0.94
MUAC change rate, mm/wk	3590	37.0 ± 88.2	1433	37.2 ± 88.1	1160	36.1 ± 85.6	1060	34.7 ± 89.2	0.88
BMI, kg/m^2									
1MP	3587	19.9 ± 2.3	1430	19.7 ± 2.1	1153	19.5 ± 2.0	1060	19.3 ± 1.9	***
3MP	3593	19.8 ± 2.3	1433	19.7 ± 2.1	1160	19.4 ± 2.0	1061	19.3 ± 1.9	***
Low BMI (<18.5 kg/m^2), %									
1MP	3587	27.2	1430	28.4	1153	31.0	1060	35.1	***
3MP	3593	29.2	1433	32.0	1160	33.6	1061	35.2	***
Delivery									
Birth weight, g	3637	2663.1 ± 372.8	1450	2628.1 ± 379.9	1170	2615 ± 378.2	1066	2601.0 ± 375.6	***
Low birth weight, %	3642	32.9	1452	36.4	1173	37.9	1071	38.7	***
Birth length, cm	3582	47.1 ± 2.0	1428	46.9 ± 2.0	1148	46.9 ± 2.1	1046	46.9 ± 2.0	**

Abbreviation: 1TM, 1st trimester; 3TM, 3rd trimester; 1MP, 1 mo postpartum; 3MP, 3 mo postpartum; MUAC, mid-upper arm circumference; BMI, body mass index;

1. Values are n and mean ± SD or %.

2. P-value is the ANOVA test for continuous variables or Chi-square test for categorical variables. **<0.01, ***<0.001.

Figure 6.1: Mean weight of the overall sample (◆) and of top 20 women with biggest (■) or smallest weight at 1st trimester (▲) from early pregnancy to early lactation by HFI groups

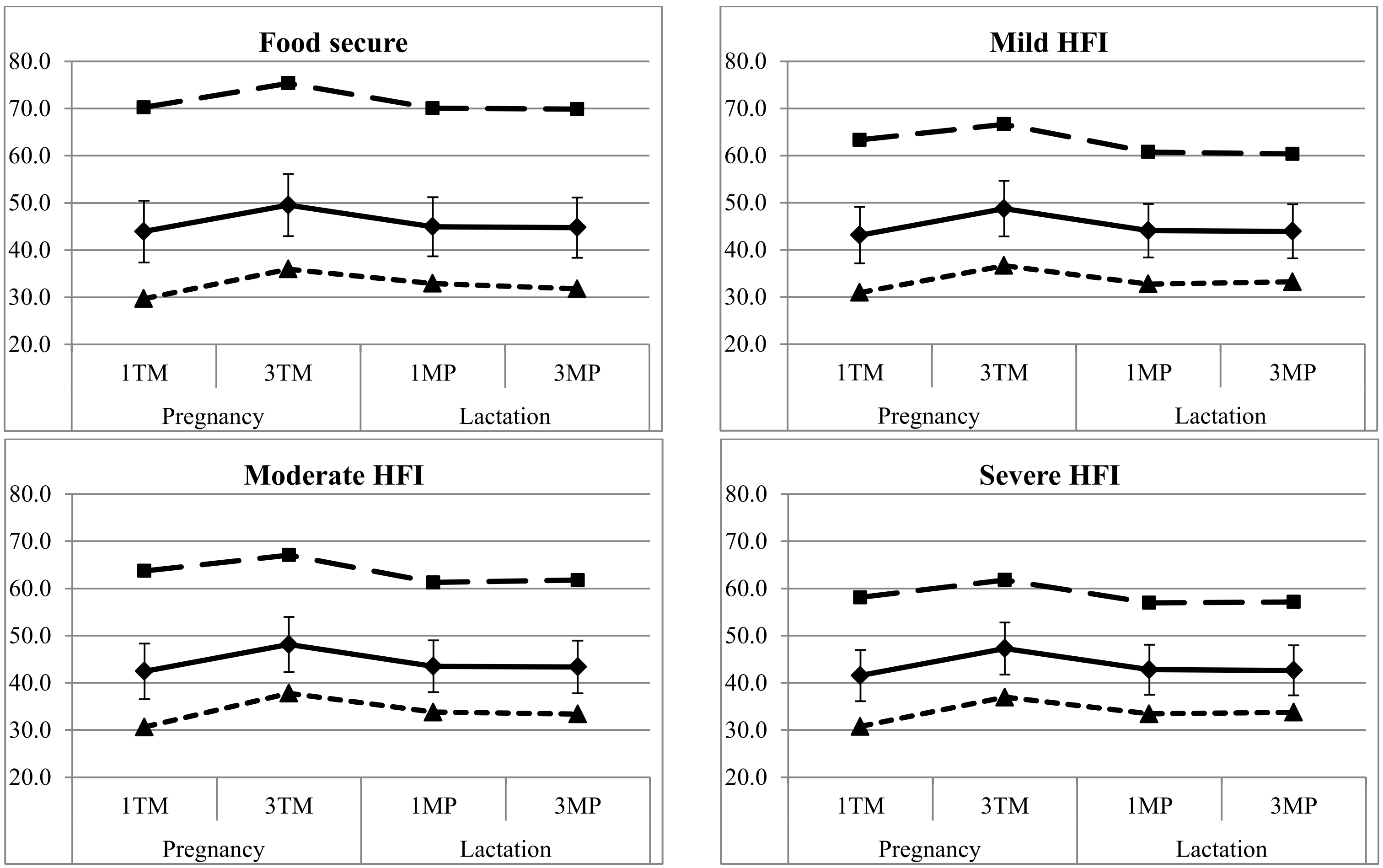

Figure 6.2: Mean MUAC of the overall sample (◆) and of top 20 women with biggest (■) or smallest MUAC at 1st trimester (▲) from early pregnancy to early lactation by HFI groups

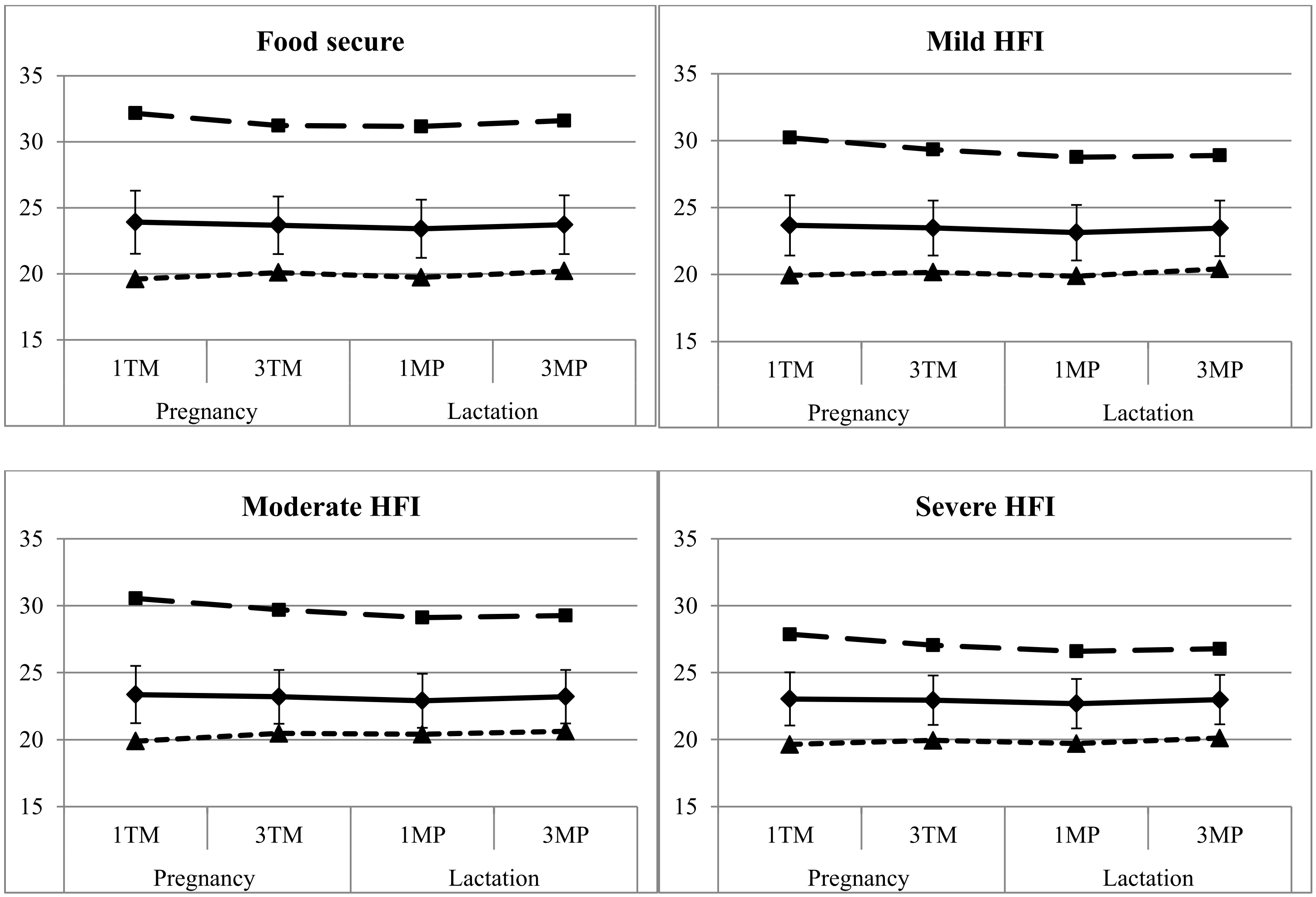

Table 6.3A: Absolute weight change during pregnancy comparing women living with household food insecurity with food secure women in different models

	Δ Weight, g					
	Model 1		Model 2		Model 3	
Exposure of interest						
HFI						
Food secure (reference)	-		-		-	
Mild	24.8	(-135.9, 185.5)	-19.5	(-171.2, 132.2)	84.5	(-66.2, 235.2)
Moderate	100.7	(-72.8, 274.3)	-20.5	(-185.0, 144.0)	141.3	(-27.5, 310.1)
Severe	144.8	(-34.9, 324.4)	-75.9	(-249.5, 97.6)	79.8	(-102.9, 262.5)
Maternal characteristics						
Age, y	-		41.5	(25.5, 57.4) ***	45.8	(29.9, 61.8) ***
Parity, n	-		-106.6	(-179.8, -33.3) **	-97.8	(-171.3, -24.2) **
BMI at 1TM, kg/m^2	-		-377.9	(-402.6, -353.1) ***	-372.2	(-396.6, -347.9) ***
GA length, wk	-		53.9	(24.2, 83.6) ***	74.2	(45.4, 103.0) ***
Any heavy physical work during pregnancy			-297.3	(-427.8, -166.8) ***	-319.9	(-446.1, -193.7) ***
Socio-economic status and seasonality						
Season of HFI assessment						
Winter (reference)	-		-		-	
Spring	-		-		-961.0	(-1200.0, -764.5) ***
Summer	-		-		-1200.0	(-1400.0, -979.2) ***
Early Monsoon	-		-		-970.0	(-1200.0, -776.8) ***
Late Monsoon	-		-		-157.5	(-355.6, 40.6)
Autumn	-		-		629.9	(419.0, 840.8) ***
Non-Muslim	-		-		82.9	(-113.3, 279.2)
Household size, n	-		-		-40.4	(-74.9, -5.9) *
Any maternal education	-		-		59.2	(-85.1, 203.4)
Wealth index	-		-		224.0	(146.1, 301.9) ***

Abbreviation: HFI, household food insecurity; 1T, 1st trimester; BMI, body mass index; GA, gestational age.
*, P<0.05; **, P<0.01; ***, P<0.001.

Table 6.3B: Absolute MUAC change during pregnancy comparing women living with household food insecurity with food secure women in different models

	Δ MUAC, cm					
	Model 1		Model 2		Model 3	
Exposure of interest						
HFI						
Food secure (reference)	-		-		-	
Mild	0.04	(-0.03, 0.11)	0.01	(-0.05, 0.08)	0.05	(-0.02, 0.11)
Moderate	0.08	(0.004, 0.16)*	-0.001	(-0.07, 0.07)	0.05	(-0.02, 0.12)
Severe	0.14	(0.06, 0.22)***	-0.002	(-0.08, 0.07)	0.03	(-0.04, 0.11)
Maternal characteristics						
Age, y	-		0.005	(-0.01, 0.01)	0.005	(-0.002, 0.01)
Parity, n	-		0.02	(-0.004, 0.06)	0.02	(-0.01, 0.05)
BMI at 1TM, kg/m^2	-		-0.17	(-0.18, -0.16)***	-0.17	(-0.18, -0.15)***
GA length, wk	-		-0.06	(-0.08, -0.05)***	-0.06	(-0.07, -0.04)***
Any heavy physical work during pregnancy	-		-0.05	(-0.09, 0.02)	-0.05	(-0.10, 0.003)
Socio-economic status and seasonality						
Season of HFI assessment						
Winter (reference)	-		-		-	
Spring	-		-		-0.54	(-0.63, -0.46)***
Summer	-		-		-0.78	(-0.85, -0.70)***
Early Monsoon	-		-		-0.61	(-0.69, -0.52)***
Late Monsoon	-		-		-0.16	(-0.24, -0.08)***
Autumn	-		-		0.31	(0.22, 0.40)***
Non-Muslim	-		-		0.08	(-0.01, 0.16)
Household size, n	-		-		-0.02	(-0.03, -0.003)*
Any maternal education	-		-		0.03	(-0.03, 0.09)
Wealth index	-		-		0.07	(0.04, 0.11)***

Abbreviation: HFI, household food insecurity; 1T, 1st trimester; BMI, body mass index; GA, gestational age.
*, P<0.05; **, P<0.01; ***, P<0.001.

Table 6.4A: Absolute weight change during lactation comparing primiparous women living with household food insecurity with food secure women in different models

	Δ Weight, g					
	Model 1		Model 2		Model 3	
Exposure of interest						
HFI						
Food secure (reference)	-		-		-	
Mild	56.6	(-121.2, 234.3)	22.1	(-153.0, 197.1)	0.2	(-178.6, 178.9)
Moderate	137.5	(-50.7, 325.8)	111.0	(-74.5, 296.5)	147.1	(-48.7, 343.0)
Severe	108.0	(-136.1, 352.1)	91.1	(-151.6, 333.8)	144.1	(-112.1, 400.4)
Maternal characteristics						
Age, y	-		13.0	(-12.9, 38.9)	11.5	(-14.7, 37.8)
Duration between assessments, wk	-		-16.6	(-81.0, 47.8)	-19.5	(-83.2, 44.3)
BMI at 1TM, kg/m^2	-		30.3	(-5.3, 65.8)	27.3	(-8.2, 62.8)
Gestational weight gain, kg	-		-125.0	(-152.2, -97.8) ***	-120.7	(-148.5, -92.9) ***
BF frequency			67.1	(-66.2, 200.4)	46.3	(-86.3, 178.9)
BF sufficiency			-170.9	(-375.4, 33.5)	-208.6	(-410.3, -6.9) *
Any heavy physical activity during last 30 d at 3MP visit	-		169.9	(-9.9, 349.7)	140.2	(-37.6, 318.0)
Socio-economic status and seasonality						
Season of HFI assessment						
Winter (reference)	-		-		-	
Spring	-		-		186.9	(-49.2, 423.0)
Summer	-		-		684.7	(449.5, 920.0) ***
Early Monsoon	-		-		100.5	(-136, 337.0)
Late Monsoon	-		-		-158.4	(-407.6, 90.7)
Autumn	-		-		292.4	(29.0, 555.8) *
Non-Muslim	-		-		193.5	(-34.7, 421.7)
Household size, n	-		-		-39.8	(-74.9, -4.8) *
Any maternal education	-		-		61.2	(-157.8, 280.1)
Wealth index	-		-		92.2	(1.2, 183.2) *

Abbreviation: HFI, household food insecurity; 1TM, 1st trimester; 1MP, 1 month postpartum; 3MP, 3 month postpartum; BMI, body mass index; GA, gestational age; BF, breastfeeding;
*, P<0.05; **, P<0.01; ***, P<0.001.

Table 6.4B: Absolute MUAC change during lactation comparing primiparous women living with household food insecurity with food secure women in different models

	Δ MUAC, cm					
	Model 1		Model 2		Model 3	
Exposure of interest						
HFI						
Food secure (reference)	-		-		-	
Mild	-0.002	(-0.08, 0.08)	-0.02	(-0.10, 0.06)	-0.02	(-0.10, 0.06)
Moderate	0.05	(-0.04, 0.14)	0.03	(-0.05, 0.12)	0.05	(-0.04, 0.14)
Severe	-0.04	(-0.15, 0.07)	-0.07	(-0.18, 0.05)	-0.04	(-0.16, 0.07)
Maternal characteristics						
Age, y	-		0.001	(-0.01, 0.01)	-0.0005	(-0.01, 0.01)
Duration between assessments, wk	-		0.03	(0.002, 0.06) *	0.03	(0.01, 0.06) *
BMI at 1TM, kg/m^2	-		0.01	(-0.01, 0.03)	0.01	(-0.01, 0.02)
Gestational weight gain, kg	-		-0.06	(-0.08, -0.05) ***	-0.05	(-0.07, -0.04) ***
BF frequency	-		0.01	(-0.05, 0.07)	0.001	(-0.06, 0.06)
BF sufficiency			-0.04	(-0.13, 0.05)	-0.04	(-0.14, 0.05)
Any heavy physical activity during last 30 d at 3MP visit	-		0.03	(-0.05, 0.11)	0.03	(-0.05, 0.11)
Socio-economic status and seasonality						
Season of HFI assessment						
Winter (reference)	-		-		-	
Spring	-		-		0.02	(-0.09, 0.12)
Summer	-		-		0.28	(0.17, 0.39) ***
Early Monsoon	-		-		0.12	(0.02, 0.23) *
Late Monsoon	-		-		-0.25	(-0.37, -0.14) ***
Autumn	-		-		-0.05	(-0.16, 0.07)
Non-Muslim	-		-		0.03	(-0.08, 0.13)
Household size, n	-		-		-0.01	(-0.02, 0.01)
Any maternal education	-		-		0.03	(-0.07, 0.13)
Wealth index	-		-		0.03	(-0.02, 0.07)

Abbreviation: HFI, household food insecurity; 1TM, 1st trimester; 1MP, 1 month postpartum; 3MP, 3 month postpartum; BMI, body mass index; GA, gestational age; BF, breastfeeding;
*, P<0.05; **, P<0.01; ***, P<0.001.

Table 6.5A: Absolute weight change during lactation comparing multiparous women living with household food insecurity with food secure women in different models

	Δ Weight, g					
	Model 1		Model 2		Model 3	
Exposure of interest						
HFI						
Food secure (reference)	-		-		-	
Mild	66.7	(-55.9, 189.4)	77.6	(-43.4, 198.7)	66.0	(-56.8, 188.8)
Moderate	54.8	(-79.4, 189.1)	51.7	(-82.4, 185.9)	25.9	(-114.6, 166.3)
Severe	0.3	(-128.2, 128.8)	11.8	(-119.4, 143.0)	-25.7	(-168.1, 116.6)
Maternal characteristics						
Age, y	-		-8.5	(-20.7, 3.7)	-13.1	(-25.7, -0.6) *
Parity, n	-		68.2	(11.8, 124.5) *	87.3	(28.8, 145.8) **
Duration between assessments, wk	-		32.1	(-18.7, 82.9)	36.2	(-14.4, 86.8)
BMI at 1TM, kg/m^2	-		-19.5	(-39.3, 0.4)	-14.2	(-34.3, 5.9)
Gestational weight gain, kg	-		-138.5	(-156.8, -120.1) ***	-130.2	(-149.0, -111.4) ***
BF frequency			118.8	(25.9, 211.7) *	104.7	(12.8, 196.6) *
BF sufficiency			3.6	(-129.6, 136.8)	38.9	(-93.2, 171.0)
Any heavy physical activity during last 30 d at 3MP visit	-		4.5	(-98.3, 107.3)	23.0	(-78.9, 124.8)
Proceeding interpregnancy interval <18 mo vs ≥18 mo	-		158.8	(-39.1, 356.7)	108.5	(-87.4, 304.4)
Proceeding pregnancy outcome being MC or SB			-44.4	(-195.4, 106.7)	-28.5	(-178.1, 121.1)
Socio-economic status and seasonality						
Season of HFI assessment						
Winter (reference)	-		-		-	
Spring	-		-		372.8	(211.6, 534.0) ***
Summer	-		-		741.4	(588.6, 894.3) ***
Early Monsoon	-		-		382.8	(225.0, 540.6) ***
Late Monsoon	-		-		160.5	(2.7, 318.3) *
Autumn	-		-		677.6	(507.6, 847.6) ***
Non-Muslim	-		-		20.3	(-141.4, 181.9)
Household size, n	-		-		-30.9	(-62.9, 1.0)
Any maternal education	-		-		-44.9	(-155.0, 65.1)
Wealth index	-		-		11.1	(-53.4, 75.7)

Abbreviation: HFI, household food insecurity; 1T, 1st trimester; 1MP, 1 month postpartum; 3MP, 3 month postpartum; BMI, body mass index; GA, gestational age; BF, breastfeeding; MC, miscarriage; SB, stillbirth
*, P<0.05; **, P<0.01; ***, P<0.001

Table 6.5B: Absolute MUAC change during lactation comparing multiparous women living with household food insecurity with food secure women in different models

	Δ MUAC, cm					
	Model 1		Model 2		Model 3	
Exposure of interest						
HFI						
Food secure (reference)	-		-		-	
Mild	0.004	(-0.05, 0.06)	0.01	(-0.04, 0.07)	0.01	(-0.04, 0.07)
Moderate	-0.03	(-0.04, 0.14)	-0.04	(-0.10, 0.02)	-0.03	(-0.10, 0.03)
Severe	-0.02	(-0.15, 0.07)	-0.04	(-0.10, 0.02)	-0.04	(-0.11, 0.02)
Maternal characteristics						
Age, y	-		0.003	(-0.002, 0.01)	0.00001	(-0.01, 0.01)
Parity, n	-		0.01	(-0.01, 0.04)	0.02	(-0.01, 0.05)
Duration between assessments, wk	-		0.04	(0.02, 0.06) ***	0.05	(0.03, 0.08) ***
BMI at 1T, kg/m^2	-		-0.02	(-0.03, -0.01) ***	-0.02	(-0.03, -0.01) ***
Gestational weight gain, kg	-		-0.05	(-0.06, -0.05) ***	-0.04	(-0.05, -0.03) ***
BF frequency	-		0.01	(-0.04, 0.05)	0.002	(-0.04, 0.04)
BF sufficiency			-0.05	(-0.12, 0.01)	-0.03	(-0.09, 0.03)
Any heavy physical activity during last 30 d at 3MP visit	-		-0.03	(-0.08, 0.02)	-0.02	(-0.06, 0.03)
Proceeding interpregnancy interval <18 mo vs ≥18 mo	-		0.06	(-0.03, 0.15)	0.02	(-0.07, 0.11)
Proceeding pregnancy outcome being MC or SB			-0.004	(-0.07, 0.06)	0.01	(-0.06, 0.08)
Socio-economic status and seasonality						
Season of HFI assessment						
Winter (reference)	-		-		-	
Spring	-		-		0.08	(0.004, 0.15) *
Summer	-		-		0.38	(0.31, 0.45) ***
Early Monsoon	-		-		0.29	(0.22, 0.36) ***
Late Monsoon	-		-		-0.08	(-0.15, -0.01) *
Autumn	-		-		0.17	(0.09, 0.25) ***
Non-Muslim	-		-		-0.04	(-0.11, 0.03)
Household size, n	-		-		-0.003	(-0.02, 0.01)
Any maternal education	-		-		-0.04	(-0.09, 0.01)
Wealth index	-		-		0.01	(-0.02, 0.04)

Abbreviation: HFI, household food insecurity; 1T, 1st trimester; 1MP, 1 month postpartum; 3MP, 3 month postpartum; BMI, body mass index; GA, gestational age; BF, breastfeeding; MC, miscarriage; SB, stillbirth
*, P<0.05; **, P<0.01; ***, P<0.001.

Figure 6.3: Seasonal exposure during gestation and lactation

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mid-Dec	Winter
Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mid-Feb	*(ref.)*
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Mid-Feb	Spring
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mid-Apr	
Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Mid-Apr	Summer
Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Mid-Jun	
May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Mid-Jun	Early monsoon
Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Mid-Aug	
Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Mid-Aug	Late monsoon
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Mid-Oct	
Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mid-Oct	Autumn
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mid-Dec	
1TM			2TM			3TM			1MP	2MP	3MP	4MP	5MP	6MP		
Pregnancy									**Lactation**							

Delivery

Harvest (Jan-Feb)

Intermediate season (May to Mid-Sep)

Lean (little Monga) (Mid-Mar to mid-Apr)

Lean (Monga) (Mid-Sep to Nov)

Abbreviation: TM, trimester; MP, month postpartum. Calendar months are labeled at the beginning of each month.

CHAPTER 7: Household Food Insecurity and Infant Growth at 6 mo of Age in Rural Bangladesh

Abstract

Food insecurity is a major concern in rural South Asia. However, the validity of household food insecurity (HFI) indicators and the pathways by which chronic food insecurity may reduce child growth remain inadequately understood. In a cohort study of 12,693 mother-infant dyads in rural Bangladesh we examined strength of association and likely explanatory pathways linking HFI, assessed using a 9-item perception-based scale assessed at 6 month postpartum, to infant size at 6 months. Mothers were assessed early in pregnancy for anthropometric status, 7-day dietary intake, and socioeconomic status. Infants were assessed for weight, length, and arm, chest and head circumferences at birth and 6 months of age. Intensity of HFI was monotonically, negatively associated with all measures of infant size at 6 months, mostly mediated by maternal stature and wasting (mid-upper arm circumference) in the first trimester of pregnancy, and birth size adjusted for gestational age. Postnatal infant dietary and morbidity exposures and household socioeconomic status explained only small and non-significant fractions of the food insecurity-related mid-infancy growth deficit. Infant size at 6 months of age was strongly associated with perceived HFI. However, this association is mediated mostly by maternal nutritional and health stresses in early pregnancy rather than post-natal infant diet and morbidity. Improving food security prior to pregnancy and during gestation may be required to attenuate associated infant undernutrition and poor growth.

Introduction

Food insecurity is a global concern and entrenched problem in rural South Asia, periodically amplified by seasonality, economic crises and effects of climate change (1). In the period 2010-12, the number of undernourished people estimated by the Food and Agricultural Organization (2) was 870 million worldwide, with a largest fraction of 35% or 304 million living in Southern Asia. Coexisting with widely prevalent food insecurity is a high burden of preschool child stunting, affecting 36%, or 69 million of its young children in the south-central Asia region in 2011 (3). Among the most affected groups are children in rural Bangladesh where, based on the most recent demographic data from 2011, 43%, 16%, and 39% of preschoolers are stunted, wasted and underweight (4).

Household food insecurity (HFI) could influence young child growth via several pathways, as has long been captured in the UNICEF framework for malnutrition (5). Maternal nutritional status, before and during pregnancy, is a strong determinant of intrauterine growth (6-8), which in turn is positively associated with postnatal linear growth (9, 10). HFI has been linked with insufficient food access to women of reproductive age extending through pregnancy and lactation (11-16). HFI is also known to alter maternal-infant interactions (17) and feeding behaviors (18, 19), factors that are identified in the UNICEF framework to be underlying causes of childhood undernutrition. Finally, HFI may contribute to increased illness (20) and mortality (21) among infants and young children, albeit through complex, interacting pathways. One pathway could be the increased vulnerability to infectious morbidity through the malnutrition-infection vicious cycle in the context of poor sanitation (22, 23), while another one may be related to changes in child care practices (24, 25) due to maternal depression caused by food scarcity (24, 26, 27). Given the complexity of mechanisms, prospective studies that can follow and partition components of likely causal pathways toward HFI and its nutritional consequences may enable a greater understanding of the ways in which food insecurity may affect infant and child growth.

In this study, we investigated the association between HFI and infant size and risk of malnutrition at the age of 6 mo using data from a pregnancy cohort in which we measured nutritional status of both mothers early in pregnancy, and infants at birth and mid-infancy, as well as feeding practices, morbidity and socioeconomic status. Our aim has been to identify components and likely mechanisms explaining any observed associations between HFI and infant size at 6 months of age in rural Bangladesh.

Methods

Mothers and infants

Subjects for this study were rural Bangladeshi mothers, with their 6-month old infants, who participated in a large, cluster-randomized trial designed to examine the efficacy of a daily antenatal supplement, containing 15 micronutrients, compared to folic acid and iron use alone, on improving fetal and infant health and survival (28). The trial was undertaken in Gaibandha and Rangpur Districts, covering an area of ~435 sq km with a population of ~650,000 (29). Married women of reproductive age (13-45 years) living in 19 contiguous unions were placed under a 5-weekly, home-based pregnancy surveillance, during which they were asked about having menstruated in the previous month. Amenorrheic women were offered a urine test to confirm pregnancy and, if pregnant, consented and begun to receive study supplements on a weekly basis through

12 weeks post-partum. Usually within a week after recruitment, women were revisited at home, asked about previous pregnancy history, frequency of dietary intake of 32 food in the previous 7 days, weighed on SECA digital scales (UNICEF) to the nearest 100 g, measured in terms of height using a portable stadiometer and left mid-upper arm circumference (MUAC) with an insertion tape (30), both to the nearest 0.1 cm. For height and MUAC, the median of triplicate measurements was taken as the representative value. Parity was counted as the number of previous live births. Women's gestational age at first anthropometric measurement was calculated as the difference between the measurement date and the date of last menstrual period (LMP). Women's dietary diversity scores (WDDS) were calculated as the total number of food groups consumed out of 10 food groups (31) in the previous week: non-rice starchy staples, dark green leafy vegetables (DGLV), vitamin-A rich fruit and vegetables (VAFV), other fruits and vegetables, legumes and nuts, organ meat, meat, fish, eggs, and dairy. Maternal body mass index (BMI) was calculated as weight/ height^2 (kg/m^2). Wealth index (WI) calculated using household socioeconomic status variables was based on a previously standardized methodology (32).

A community-based birth notification system was set up to enable trained field staff to visit mothers and newborn children usually within a week after birth to assess infant size. Naked birth weight of infants was measured to the nearest 10 g on a TANITA BD-585 scale (Tanita Corporation, Arlington Heights, IL); recumbent length was measured using a portable, plexiglass, folding length board with fixed head piece and sliding foot block modified from the Infant Shorr board and head, chest and left mid-upper arm circumference measurements were taken using an Ross insertion tape (Abbott

Laboratories), all to the nearest 0.1 cm, following previously described methods (33). Gestational age (GA) in weeks at birth was calculated based on the interval between the dates of LMP and delivery. Preterm birth was defined as less than 37 weeks of GA before delivery. At 6 months postpartum infants were revisited to evaluate vital status, anthropometric status by the same procedures, breast feeding frequency and sufficiency, introduction of non-breast milk foods, and histories of morbidity symptoms in the previous 7 days including acute respiratory, diarrhea, dysentery and fever. Added food items were reported by 11 food groups (34): 1) Infant formula; 2) milk; 3) dairy; 4) plain water; 5) any grains; 6) dal; 7) banana; 8) biscuit; 9) added oil; 10) added sugar, and 11) other food. Infant BMI at ~6 mo was calculated as weight/ height^2 (kg/m^2), whereas an infant's ponderal index (PI) at birth was calculated as weight/ height^3 (kg/m^3). Infant weight and length measurements were converted to weight-for-length (WLZ), weight-for-age (WAZ), and length-for-age (LAZ) z-scores using the World Health Organization (WHO) Multicenter Growth Reference Study child growth standards, using WHO Anthro Version 3.2.2 (WHO, Geneva, Switzerland). Wasting, stunting and underweight were defined as <-2 z-score for WLZ, LAZ and WAZ, respectively.

Household food security

At 6 month postpartum, household food insecurity was measured by using a 9-item Food Access Survey Tool (FAST) on a Likert scale, which was developed and tested by Food and Nutrition Technical Assistance Project in Bangladesh (35). The FAST reflects the concept of food security in four domains: anxiety over food acquisition, quality of food, quantity of food, and social acceptability. Households with negative answers to all nine items were defined as food secure. The rest of households were then categorized as having mild, moderate and severe HFI based on the tertile cutoffs of non-zero summed scores of the 9 items. Six standard seasons were defined based on HFI assessment date using the Bangladeshi calendar starting from the middle of December for every two months (36).

Statistical analysis

All of results were reported by HFI index category, where HFI is treated as a categorical variable. Chi-square tests were used to compare maternal, infant and household characteristics between HFI groups. Nonparametric tests for linear trend across the ordered HFI groups were applied on maternal and infants' anthropometric measures. To study the pathway of HFI on early infant growth, we developed a conceptual framework, hypothesizing a maternal-pregnancy-nutrition pathway likely mediated by alteration in feeding practices and infant morbidity (**Figure 7.1**). A set of multiple linear regression models were applied with cumulative adjustment on a temporal sequence starting from nutritional status of mothers at early pregnancy, followed by birth size as a proxy for fetal growth outcome, and then the postnatal influences via diet, morbidity, socio-economic status (SES) and seasonality. Similarly, a set of multiple logistic regression models were used with the same adjustment procedure to study HFI and risk of wasting, stunting and underweight at 6 mo of age. Specifically, maternal height, MUAC and WDDS were used as indicators for maternal nutritional status and GA-adjusted birth length and the length-adjusted birth weight, ponderal index (PI), were used as birth size proxies. Feeding practices and child morbidity that were found significantly different with HFI status were included in the multiple regression models. SES variables included in adjustments were maternal employment, maternal education, and wealth index (WI). Other important factors that were associated with prenatal and postnatal growth were adjusted in the regression analysis prior to the introduction of the temporal sequence adjustment. These factors include maternal parity, age and GA at maternal anthropometric assessment, infant sex and age in month at 6 mo follow up. We set the primary level of statistical significance at $p<0.05$. All analyses were performed using R 2.13.2 (The R Foundation for Statistical Computing).

Results

Out of 18,841 participating women-infant pairs, 18,288 had complete data at maternal and SES assessment at enrollment. Among those 18,288 identified births, 15,051 (82.3%) singletons were able to be assessed within one week (<168 h) after delivery; this number resulted from 160 twins (0.9%), 182 lost to follow-up (1.0%), and 2,895 measured beyond a one-week window (15.8%). At 6 mo postpartum, 927 (5.1%) subjects were lost to follow-up. We further excluded subjects with missing data in the following: gestational age (n=567, 3.1%), anthropometry measures at birth (n=319, 1.7%) and at 6-month follow-up (n=439, 2.4%), food security questions (n=2, <0.1%), feeding practice measures (n=99, 0.5%) and morbidity histories (n=5, <0.1%). Therefore we kept 12,693 (69.4%) mother-infant pairs in this analysis (**Figure 7.2**): 6171 (48.6%), 2600 (20.5%), 1982 (15.6%), and 1940 (15.3%) households were categorized as food secure, mildly food-insecure, moderately food insecure and severely food insecure, respectively.

Comparisons of women, infants and SES characteristics by HFI were demonstrated in **Table 7.1**. On average, 73.7% and 24.8% of all mothers were measured within the first and second trimester of pregnancy respectively, and these percentages did not differ by HFI groups. Mothers in food insecure groups tended to be older in age, to have more parity, and to consume a less diverse diet than more food secure women (all $p<0.001$). Infant age at 6 mo follow-up ($p=0.37$) and infant sex ($p=0.09$) did not differ by HFI status, although a lower proportion of female babies was observed among the severe HFI households. Risk of preterm birth rose monotonically from 16.9% in the food secure group to 20.9% in the severe HFI group ($p<0.001$). While current breastfeeding at 6 months was universal (all 100%), the reported frequency ($p=0.06$) and sufficiency ($p<0.001$) of breastfeeding in the previous day decreased with increased HFI severity. The proportion of feeding formula, milk (powdered or fresh) or dairy food dropped linearly from food secure to food insecure households (all $p<0.001$). Feeding plain water was commonly practiced by 77.7% of all women on average and was not differentiable by HFI status ($p=0.32$). Similar trends were seen in feeding semi-solid and solid foods: among commonly added food items such as foods made from grains (62.2%, $p=0.57$) and biscuit (55.0%, $p=0.20$), there was an equal distribution of such feeding practices across HFI groups. A general negative linear association was observed between increased HFI and a decrease in the proportion of feeding dal, banana, oil, sugar (all $p<0.001$) and other foods ($p<0.05$). Infants of food-insecure households were more frequently ill for all 4 common infections in the previous 7 days than those from more food secure households (all $p<0.01$). SES variables were all significantly different by HFI status. Mothers progressively had less education as their HFI became more severe. However, the proportion of maternal employment differed across HFI groups in a non-linear way ($p<0.001$): 42.5% of mothers suffering severe HFI worked paid jobs, a proportion just slightly lower than the food secure group (42.6%) but higher than mothers from mild (39.9%) and moderate (37.6%) households. Among food secure households, 17.5% and 48.1% were in the lowest and highest wealth index (WI) tertile. The number gradually switched from 37.0% and 22.7%, and 50.9% and 13.0%, to 66.1% and 5.9% for the mild, moderate and severe HFI categories, respectively ($p<0.001$). The season during which food insecurity was assessed showed heterogeneity in distribution by HFI groups ($p<0.001$). The maternal and infant anthropometric variables were normally distributed. As **Table 7.2** shows, all anthropometric variables of women at early pregnancy, and of infants at birth and ~6 months of age, were negatively associated in a linear trend with increasing severity of food insecurity (all $p<0.001$).

Mean infant size deficits comparing HFI groups against the food-secure reference group from the stepwise regression analyses were presented in **Table 7.3**. HFI has a significant dose-responsive association with infant weight, length, body mass index (BMI), and circumferences in the mid-upper arm (MUAC), head (HC), and chest (CC) at 6 months of age. Compared with the reference, mean differences in child sizes were negative and the deficits enlarged progressively from the mild through the moderate to severe HFI group. Such dose-responsive relationships held true in the unadjusted models and along the cumulatively adjusted models in general. In all three HFI groups, the deficits in child sizes decreased with the sequential adjustments, except after adjusting for non-breast milk feeding practices, in which the size deficits became slightly greater. Compared with the unadjusted models, the decreasing trend in size deficits occurred largely after adjusting for maternal nutrition (MUAC and height) and birth size (infant's GA, birth length and PI), by 39-67% and 11-33%, respectively. Together maternal nutrition and birth sizes explained 57-89% of the size deficits found in unadjusted models. Postnatal factors, such as feeding practices and child morbidity altogether, further brought down the mean size differences by another 0-17%. Other contextual variables, including maternal employment, maternal education, WI and seasonality, explained 0-36% of the remaining differences in infant sizes. Because of the substantial reduction in effect size, almost all size differences lost statistical significance after birth size variables were adjusted.

Table 4 showed the estimated relative risk of mid-infancy malnutrition with similar sequential adjustments. Risk of wasting in the mild or moderate group was not different at any level of adjustment compared to infants from food-secure families. Severe HFI was associated with a 36% (95%CI: 14%, 61%) increased odds of being wasted, which decreased to 17% (95%CI: -3%, 40%) after adjustment for maternal nutrition and remained insignificant thereafter. The dose-responsive relationship was observed between HFI and risk of infant stunting and underweight. Compared with the food secure group in the unadjusted models, mild, moderate and severe HFI were associated with a 6%, 27%, and 39% increased risk for stunting and an 18%, 37% and 62% increased risk for underweight, respectively. After adjusting for maternal MUAC and height, relative to infants from the reference group, the increased odds of stunting and underweight in ascending order of HFI categories dropped to -3%, 10% and 16%, and to 8%, 19% and 32%, respectively, about halved from their unadjusted level. After birth size adjustment, risk of stunting and underweight decreased by another 5.8% on average for all HFI groups to an insignificant level. Exceptionally, severe HFI was still significantly associated with a 25% (95%CI: 9%, 42%) increased risk of underweight at this point, which went down to 17% (95%CI: 2%, 34%) when accounting for postnatal feeding practices and morbidity variables and then to an insignificant level of 7% in the full model with SES variables and seasonality. Compared with the food secure group, mild HFI was now associated with a 13% (95% CI: 1%, 24%) lower risk of mid-infancy stunting in the full model.

Discussion

Within this typical rural setting of northern Bangladesh, we sought to explore the relationship between household food insecurity (HFI), assessed by a nine-item questionnaire, and mid-infancy anthropometric indicators of wasting and stunting malnutrition. We reasoned that a family's level of perceived food insecurity, if sufficiently severe and extended, may affect attained postnatal growth. Further, we sought to identify determinants of any observed association by introducing potentially causal, antecedent indicators of maternal nutritional status early in pregnancy, newborn gestational age and size reflecting health and nutrition during gestation, postnatal dietary and morbidity exposures and household socioeconomic conditions that could explain the association between HFI and mid-infancy status.

Our findings revealed a consistent, dose-response decline in attained infant ponderal and linear growth at six months of age with increasing severity of a home food insecurity index. Infants from households classified as severely food insecure were 184 grams lighter, 0.45 cm shorter, 0.2 cm less in arm and head circumferences, 0.4 cm less in chest circumference, and 0.23 kg/m^2 less than infants in food secure homes. Further, each decrement in HFI from adequacy was associated with dose-response increases in risks of being underweight and stunted, reflected by weight and length for age being below -2 z-scores, respectively, at 6 months of age. The risk of wasting (<-2 z-scores in weight for length) was only significantly higher for infants of severely food insecure households, suggesting that underlying determinants were likely to be of a longer than shorter term nature.

Our cross-sectional associations were consistent with many, though not all, studies among different aged children using a similar HFI scale in resource-limited environments (37-39). A pooled analysis of data from four South Asian, two Sub-Saharan Africa and two Latin American countries found a 0.2 standard deviation decrease in height-for-age z-scores among children aged 2-5 years for each 10-point score increase in household food insecurity (37). In Pakistan, infants 6-18 months of age from in food insecure households reporting hunger in the past 12 months were 3 times more likely to be stunted than children from food secure homes (38). A dose-response relationship was also documented among preschool children in Colombia (39), where mild, moderate and severe HFI was associated with 28%, 58%, 65% increased odds of stunting and 11% ($p>0.05$), 47%, 89% increased odds of being underweight after controlling for demographic and socioeconomic factors. Elsewhere in Bangladesh, Saha et al observed risks of stunting and underweight from 1 through 24 months of age to be lowest in food secure and highest the most food insecure households (40). However, in cross-sectional studies in Nepal (41) and Sri Lanka (42), researchers failed to observe growth faltering in preschoolers from food insecure homes.

While we observed a linear decline in arm circumference and BMI with household food insecurity, risk of wasting below -2 z-scores was increased only within severely insecure homes, as found elsewhere in Bangladesh (40) but either not reported (38, 42) or found null effect in other countries (37, 39, 41). A less consistent association with child wasting suggests that food insecurity, as classified by perception-based questions, may be more strongly representing long-term than acute food deprivation (43).

A unique feature of our study was a prospective design that enabled us to identify and partition, through a stepwise procedure, effects of potential maternal mediators of the HFI-infant malnutrition association. In rural Bangladesh, women may compromise their own energy intake (44, 45) and dietary diversity (46) to ensure adequacy of diet for their husbands and young offspring. Furthermore, a clear linkage has been made between household food insecurity and quality and energy of a women's diet in other poor societies (14-16), suggesting maternal nutritional status may be a sensitive indicator of HFI. Importantly, we observed that half or more of all infant size deficits linked to post-partum food insecurity were explained by maternal nutritional factors before or during pregnancy, representing a period of a year or more before the 6-month recall period. Specifically, maternal height, reflecting, in part, long-term nutritional consequence (47), explained a 23-30% and 28-38% of the food security-related weight and length deficit of infants at six months of age. While mechanisms remain poorly understood, shorter maternal stature is a known contributor to smaller birth size and increases risk of infant and childhood malnutrition (43). Maternal arm circumference explained additionally ~14-21% of an infant's unadjusted weight and 7-11% of the length deficit associated with HFI, consistent with data that link maternal nutritional status during pregnancy to fetal (48) and postnatal growth (49). Finally, using birth length as an indicator of the adequacy of growth throughout gestation (50, 51) and ponderal index to reflect especially late gestation fetal weight gain (52), we estimated that nutritional, hormonal and disease factors regulating these facets of growth explained 17-20% of the food insecurity-related deficit in weight and 11-20% of the associated deficit in length at six months of age, independent of maternal nutritional status near the outset of pregnancy.

Postnatal breast and complementary feeding practices, coupled with recorded morbidity experiences recorded during the actual recall period accounted for small (6-13% and 4-7%, respectively) and non-significant fractions of the food insecurity-related, mid-infancy ponderal and linear growth deficits. Maternal and household socioeconomic factors accounted for virtually all of the infant growth deficit associated with levels of household food insecurity, albeit minor remaining decrements in our statistical models. Interestingly, another recent study failed to find child dietary diversity mediating the relationship between HFI and preschool child undernutrition in Bangladesh, Ethiopia and Vietnam (53). The authors speculated that the strong associations between HFI and adequacy of child size may be explained by maternal wasting and undernutrition before and during pregnancy, as we have shown in this large prospective study.

Sensitivity analyses were performed to address the concern of the order of adjustment in the cumulative regression analysis. First, after the adjustment of fixed variables of infant sex, age and maternal parity, age and GA, a reverse order of adjustment was applied starting from postnatal factors and followed by birth size and maternal nutritional status (**Appendix 7.4**). If results were not sensitive to the order of adjustment, switching the order should not change the relative reduction in effect size.

Postnatal factors (breastfeeding, non-breast milk food feeding and morbidity), when adjusted first, explained less than a third of the variances observed in the unadjusted models of HFI on infant weight and length at 6 mo of age. Together infant size and maternal nutritional status accounted for 46.4-68.9% of the variances, a percentage that was smaller than the presented data (57.1-86.7% for infant weight and length). However, the conclusion remained the same that maternal nutrition at early pregnancy and infant size at birth explained the majority of infant size deficits associated with HFI at 6 month of age. The other sensitivity analysis was performed with adjustment on SES factors first and followed by fixed factors and factors along the nutritional pathway (**Appendix 7.5**). As shown by the data in Appendix 7.5, the association between HFI and infant size quickly went to insignificant level with adjustment of SES, as well measured by wealth index, maternal education and maternal employment. SES as a strong, complex determinant of food insecurity, also influences infant growth through complicated pathways. However, none of these SES components reveal causal pathways by which infant growth faltering occurs. A recent Lancet paper showed small to null association between increases in per capita gross domestic product and reduction in child undernutrition among children aged 0-35 months, indicating the need of direct nutrition and health interventions that can be translated into nutritional improvement (53). The presented analysis in this paper seeks to identify and quantify proximal determinants of this long-term pathway linking HFI and infant size. Therefore, we present the results from cumulative regression models with the current order of adjustment.

Conclusion

Persistent food insecurity was found reducing early infant growth mainly through a materno-feto-infant nutritional pathway. Future policies to address food insecurity induced maternal and infant malnutrition should emphasize in women early in and likely long before pregnancy.

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Figures and Tables for Chapter 7

Figure 7.1: Conceptual framework of the association between household food insecurity and infant size at 6 mo

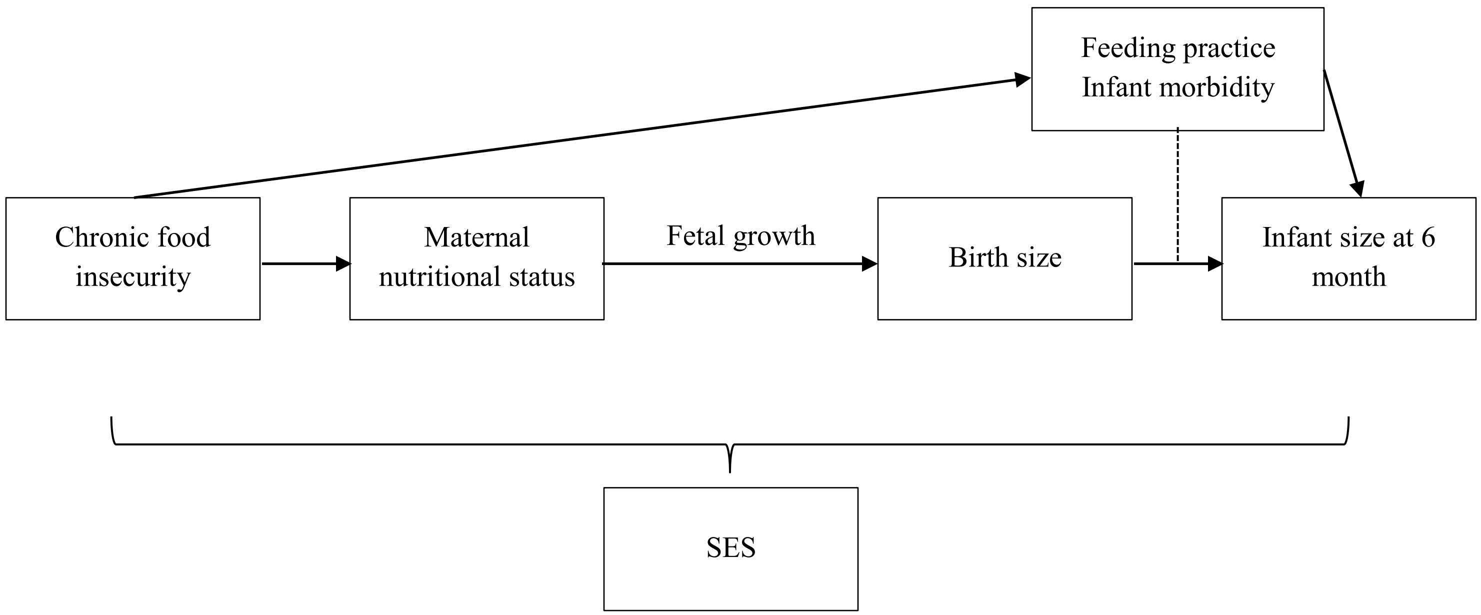

Figure 7.2: Study population and food security categorization

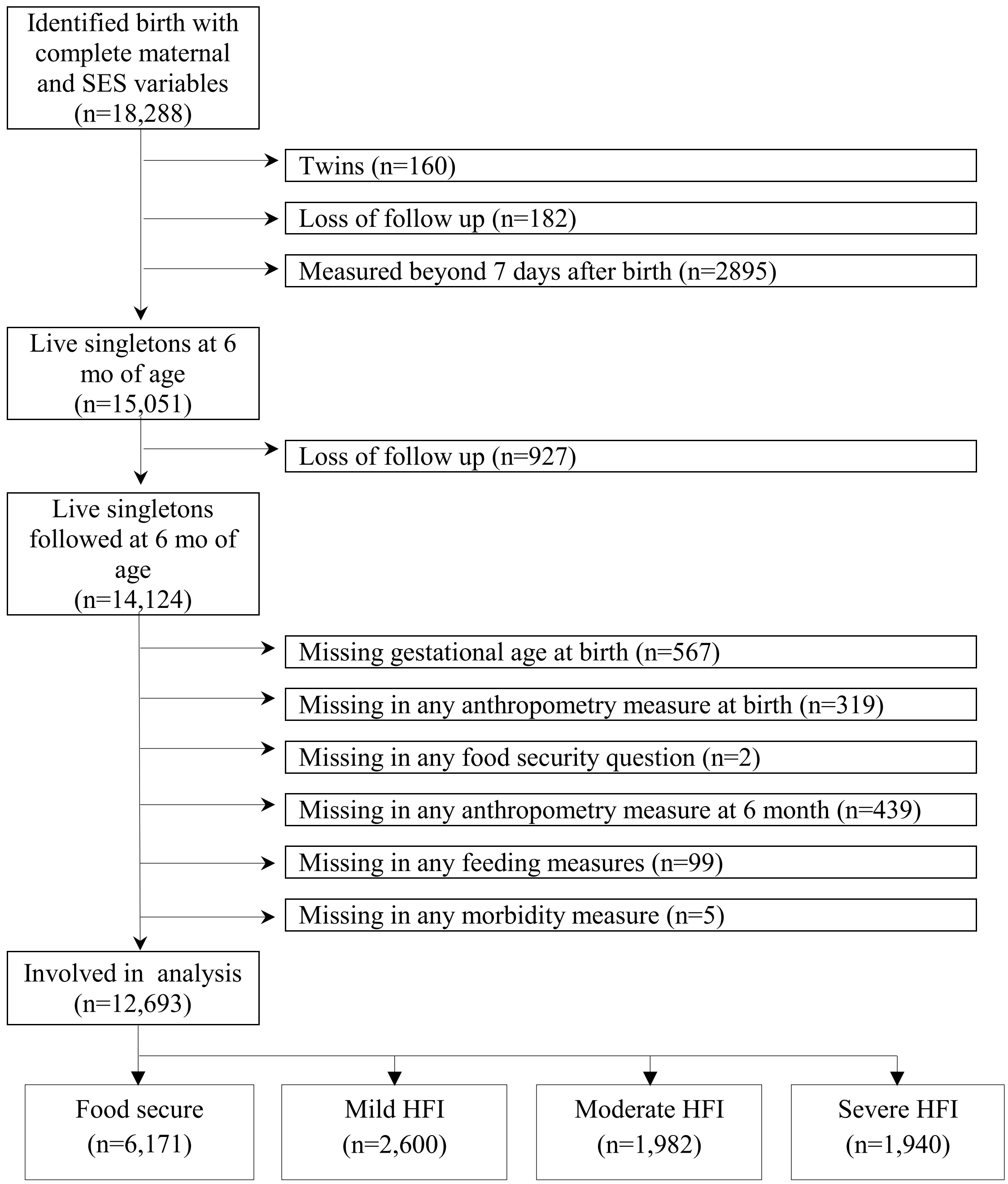

Table 7.1: Characteristics of women, infants and household by household food security category (N=12,693)[1]

	Food secure (n=6,171)	Food insecurity Mild (n=2,600)	Moderate (n=1,982)	Severe (n=1,940)	p-value
Mothers					
GA at measurement, wk					0.65
≤12	73.7	73.0	74.4	73.8	
≤27	24.8	25.5	24.2	24.2	
>27	1.4	1.5	1.4	2.0	
Age, y					***
<20	30.4	34.7	35.4	22.6	
20-29	57.0	55.5	52.3	56.9	
>29	12.7	9.8	12.3	20.5	
Parity, n					***
0	36.8	36.7	36.7	22.0	
1	37.0	36.0	31.5	28.5	
2	17.7	18.1	18.8	24.4	
3	5.7	6.1	8.8	14.3	
≥4	2.8	3.1	4.1	10.8	
Dietary diversity score tertiles					***
Low	35.4	44.0	49.3	57.7	
Medium	42.4	40.3	38.5	33.6	
High	22.2	15.8	12.2	8.7	
Infants					
Age at assessment, mo					0.37
<6	0.3	0.3	0.6	0.6	
6-7	99.1	99.1	98.8	99.0	
≥8	0.6	0.6	0.6	0.5	
Female	48.7	49.8	49.4	46.2	0.09
Preterm birth	16.9	18.9	17.7	20.9	***
Current BF	100.0	100.0	100.0	100.0	
BF frequency a day, n					0.06
1-10	11.2	11.9	12.6	13.7	
11-20	73.7	74.2	73.8	72.3	
≥ 21	15.0	13.9	13.6	14.0	
Had enough BF	76.2	72.5	70.6	63.3	***
Any food group given last week					
Infant formula	10.7	6.9	5.0	3.5	***
Milk (powdered or fresh)	24.1	19.5	16.6	16.1	***
Dairy	6.1	5.2	3.9	2.9	***
Water	77.2	78.8	78.3	77.2	0.32
Any grains	61.6	62.6	62.9	63.0	0.57
Biscuit	54.5	56.0	56.6	53.9	0.20
Dal	4.8	4.5	2.7	2.8	***
Banana	11.6	10.0	10.4	8.2	***
Added oil	28.9	31.0	27.9	25.9	***
Added sugar	33.9	33.1	29.8	29.3	***
Other food	24.6	24.8	23.0	21.4	*
Any symptom last week					
Acute respiratory infections	61.3	63.9	63.9	67.4	***
Diarrhea	2.7	3.1	4.4	4.6	***
Bloody stools	1.6	1.3	1.6	2.7	**
Fever	12.9	13.4	14.0	16.3	**

(Table 7.1 cont'd)

	Food secure (n=6,171)	Food insecurity Mild (n=2,600)	Moderate (n=1,982)	Severe (n=1,940)	p-value
Socio-economic variables					
Maternal education (any schooling)	83.8	76.1	66.7	52.4	***
Maternal paid job	42.6	39.9	37.6	42.5	***
Wealth index tertiles					***
Low	17.5	37.0	50.9	66.1	
Medium	34.3	40.3	36.2	28.0	
High	48.1	22.7	13.0	5.9	
Season of HFI assessment					***
Winter	15.1	15.6	14.4	16.5	
Spring	17.2	18.1	21.2	18.4	
Summer	19.3	21.8	21.2	19.7	
Early Monsoon	19.2	16.0	14.2	13.4	
Later Monsoon	16.5	14.3	14.9	14.6	
Autumn	12.6	14.1	14.0	17.3	

Abbreviation: GA, gestational age; BF, breastfeeding;
1. Values are %. Sample size is the same for moms and infants.
2. P-value is the Chi-square test across HFI groups. * <0.05, **<0.01, ***<0.001

Table 7.2: Women and infant anthropometry by household food insecurity category[1]

		Food insecurity			
	Food secure (n=6,171)	Mild (n=2,600)	Moderate (n=1,982)	Severe (n=1,940)	p-value
Mothers					
Weight, kg	44.2 ± 6.5	43.2 ± 6.0	42.5 ± 5.7	42.0 ± 5.5	***
Height, cm	150.2 ± 5.1	149.6 ± 5.2	149.2 ± 5.0	148.8 ± 5.4	***
MUAC, cm	23.8 ± 2.3	23.5 ± 2.2	23.3 ± 2.1	23.0 ± 2.0	***
BMI, kg/m^2	19.5 ± 2.5	19.3 ± 2.3	19.1 ± 2.2	18.9 ± 2.1	***
Infant at birth					
Weight, g	2612 ± 401	2571 ± 400	2550 ± 396	2555 ± 406	***
Height, cm	46.8 ± 2.1	46.6 ± 2.2	46.6 ± 2.2	46.6 ± 2.2	***
MUAC, cm	9.6 ± 0.8	9.5 ± 0.8	9.5 ± 0.8	9.5 ± 0.8	***
HC, cm	32.8 ± 1.5	32.6 ± 1.5	32.6 ± 1.5	32.6 ± 1.6	***
CC, cm	31.0 ± 2.0	30.8 ± 2.0	30.8 ± 2.0	30.7 ± 2.0	***
PI, kg/m^3	25.3 ± 2.4	25.2 ± 2.4	25.1 ± 2.4	25.1 ± 2.5	***
Infants at 6 month visit					
Weight, g	6732 ± 849	6639 ± 819	6602 ± 848	6548 ± 862	***
Height, cm	64.4 ± 2.5	64.1 ± 2.4	64.0 ± 2.5	64.0 ± 2.6	***
MUAC, cm	13.3 ± 1.0	13.3 ± 1.0	13.2 ± 1.0	13.1 ± 1.0	***
HC, cm	41.6 ± 1.4	41.5 ± 1.3	41.5 ± 1.4	41.4 ± 1.4	***
CC, cm	42.4 ± 2.1	42.2 ± 2.0	42.1 ± 2.1	42.0 ± 2.2	***
BMI, kg/m^2	16.2 ± 1.5	16.1 ± 1.5	16.1 ± 1.5	16.0 ± 1.5	***

Abbreviation: MUAC, mid-upper arm circumference; BMI: body mass index, calculated as weight (kg)/[length(m)^2]; HC, head circumference; CC, chest circumference; PI, ponderal index, calculated as weight (kg)/[length(m)^3]

1. Values are mean ± SD. Sample size is the same for moms and infants.

2. P-value is the non-parametric test for linear trend across HFI groups. Significance for p-values: * <0.05, **<0.01, ***<0.001

Table 7.3: Mean differences in infant size at 6 mo by cumulative adjustment comparing infants from food-insecure households with infants from food-secure households (reference group)[1]

Model index	Variable added	Weight, g			Length, cm			BMI, kg/m^2		
		Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
1	HFI (unadjusted)	**-93 ± 20**	**-130 ± 22**	**-184 ± 22**	**-0.28 ± 0.06**	**-0.40 ± 0.06**	**-0.45 ± 0.07**	**-0.08 ± 0.03**	**-0.12 ± 0.04**	**-0.23 ± 0.04**
2	Infant sex + age	**-86 ± 18**	**-125 ± 20**	**-196 ± 21**	**-0.26 ± 0.05**	**-0.39 ± 0.06**	**-0.48 ± 0.06**	**-0.08 ± 0.03**	**-0.11 ± 0.04**	**-0.25 ± 0.04**
3	Parity+ maternal age +maternal GA	**-79 ± 19**	**-115 ± 20**	**-184 ± 21**	**-0.23 ± 0.05**	**-0.36 ± 0.06**	**-0.48 ± 0.06**	**-0.07 ± 0.03**	**-0.10 ± 0.04**	**-0.21 ± 0.04**
4	Maternal height	**-58 ± 18**	**-78 ± 20**	**-133 ± 20**	**-0.15 ± 0.05**	**-0.21 ± 0.06**	**-0.28 ± 0.06**	-0.06 ± 0.03	**-0.09 ± 0.04**	**-0.19 ± 0.04**
5	Maternal MUAC	**-44 ± 18**	**-54 ± 20**	**-94 ± 20**	**-0.13 ± 0.05**	**-0.18 ± 0.06**	**-0.23 ± 0.06**	-0.04 ± 0.03	-0.05 ± 0.04	**-0.12 ± 0.04**
6	WDDS	**-40 ± 18**	**-46 ± 20**	**-84 ± 20**	**-0.12 ± 0.05**	**-0.15 ± 0.06**	**-0.19 ± 0.06**	-0.03 ± 0.03	-0.04 ± 0.04	**-0.12 ± 0.04**
7	Infant's GA at birth	**-37 ± 18**	**-47 ± 20**	**-81 ± 20**	**-0.10 ± 0.05**	**-0.15 ± 0.06**	**-0.18 ± 0.06**	-0.03 ± 0.03	-0.04 ± 0.04	**-0.12 ± 0.04**
8	Birth length[2]	-29 ± 16	-31 ± 18	**-60 ± 18**	-0.07 ± 0.04	**-0.09 ± 0.05**	**-0.1 ± 0.05**	-0.03 ± 0.03	-0.03 ± 0.04	**-0.11 ± 0.04**
9	Ponderal index[3]	-21 ± 15	-16 ± 17	**-45 ± 18**	-0.07 ± 0.04	-0.09 ± 0.05	-0.09 ± 0.05	-0.01 ± 0.03	0 ± 0.04	-0.07 ± 0.04
10	BF practices[4]	-14 ± 15	-6 ± 17	-22 ± 18	-0.06 ± 0.04	-0.08 ± 0.05	-0.07 ± 0.05	0 ± 0.03	0.02 ± 0.04	-0.03 ± 0.04
11	CF practices[5]	-16 ± 15	-9 ± 17	-25 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05	0 ± 0.03	0.01 ± 0.04	-0.04 ± 0.04
12	Child morbidity[6]	-16 ± 15	-7 ± 17	-21 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.06 ± 0.05	0 ± 0.03	0.01 ± 0.04	-0.03 ± 0.04
13	Maternal employment[7]	-16 ± 15	-7 ± 17	-21 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05	0 ± 0.03	0.01 ± 0.04	-0.03 ± 0.04
14	Maternal education[8]	-11 ± 15	0 ± 17	-12 ± 18	-0.05 ± 0.04	-0.05 ± 0.05	-0.04 ± 0.05	0 ± 0.03	0.02 ± 0.04	-0.02 ± 0.04
15	Wealth index	1 ± 16	17 ± 18	8 ± 19	-0.03 ± 0.04	-0.03 ± 0.05	-0.01 ± 0.05	0.02 ± 0.03	0.05 ± 0.04	0.01 ± 0.04
16	Season	2 ± 16	18 ± 18	8 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05	0.02 ± 0.03	0.04 ± 0.04	0 ± 0.04

(Table 7.3 con't)

Model index	Variable added	MUAC, cm			HC, cm			CC, cm		
		Mild	Moderate	Severe	Mild	Moderate	Severe	Mild	Moderate	Severe
1	HFI (unadjusted)	**-0.08 ± 0.02**	**-0.14 ± 0.03**	**-0.21 ± 0.03**	**-0.08 ± 0.03**	**-0.14 ± 0.04**	**-0.19 ± 0.04**	**-0.17 ± 0.05**	**-0.31 ± 0.05**	**-0.41 ± 0.06**
2	Infant sex + age	**-0.08 ± 0.02**	**-0.13 ± 0.02**	**-0.22 ± 0.02**	**-0.06 ± 0.03**	**-0.13 ± 0.03**	**-0.22 ± 0.03**	**-0.16 ± 0.05**	**-0.30 ± 0.05**	**-0.43 ± 0.05**
3	Parity+ maternal age +maternal GA	**-0.07 ± 0.02**	**-0.12 ± 0.02**	**-0.19 ± 0.03**	-0.05 ± 0.03	**-0.12 ± 0.03**	**-0.21 ± 0.03**	**-0.14 ± 0.05**	**-0.28 ± 0.05**	**-0.40 ± 0.05**
4	Maternal height	**-0.06 ± 0.02**	**-0.10 ± 0.02**	**-0.16 ± 0.03**	-0.03 ± 0.03	**-0.07 ± 0.03**	**-0.15 ± 0.03**	**-0.10 ± 0.05**	**-0.20 ± 0.05**	**-0.29 ± 0.05**
5	Maternal MUAC	-0.04 ± 0.02	**-0.06 ± 0.02**	**-0.11 ± 0.03**	-0.01 ± 0.03	-0.05 ± 0.03	**-0.11 ± 0.03**	-0.07 ± 0.05	**-0.15 ± 0.05**	**-0.21 ± 0.05**
6	WDDS	-0.03 ± 0.02	**-0.06 ± 0.02**	**-0.10 ± 0.03**	0 ± 0.03	-0.03 ± 0.03	**-0.09 ± 0.03**	-0.06 ± 0.05	**-0.14 ± 0.05**	**-0.19 ± 0.05**
7	Infant's GA at birth	-0.03 ± 0.02	**-0.06 ± 0.02**	**-0.10 ± 0.03**	0 ± 0.03	-0.03 ± 0.03	**-0.09 ± 0.03**	-0.06 ± 0.05	**-0.14 ± 0.05**	**-0.18 ± 0.05**
8	Birth length[2]	-0.03 ± 0.02	-0.05 ± 0.02	**-0.08 ± 0.02**	0.01 ± 0.03	-0.01 ± 0.03	**-0.06 ± 0.03**	-0.04 ± 0.04	**-0.11 ± 0.05**	**-0.14 ± 0.05**
9	Ponderal index[3]	-0.02 ± 0.02	-0.03 ± 0.02	**-0.06 ± 0.02**	0.02 ± 0.03	0 ± 0.03	-0.04 ± 0.03	-0.02 ± 0.04	-0.07 ± 0.05	**-0.11 ± 0.05**
10	BF practices[4]	-0.01 ± 0.02	-0.02 ± 0.02	-0.04 ± 0.02	0.03 ± 0.03	0.01 ± 0.03	-0.03 ± 0.03	-0.01 ± 0.04	-0.05 ± 0.05	-0.06 ± 0.05
11	CF practices[5]	-0.01 ± 0.02	-0.02 ± 0.02	-0.04 ± 0.02	0.02 ± 0.03	0.01 ± 0.03	-0.02 ± 0.03	-0.01 ± 0.04	-0.06 ± 0.05	-0.07 ± 0.05
12	Child morbidity[6]	-0.01 ± 0.02	-0.02 ± 0.02	-0.04 ± 0.02	0.02 ± 0.03	0.01 ± 0.03	-0.02 ± 0.03	-0.01 ± 0.04	-0.05 ± 0.05	-0.06 ± 0.05
13	Maternal employment[7]	-0.01 ± 0.02	-0.02 ± 0.02	-0.03 ± 0.02	0.03 ± 0.03	0.02 ± 0.03	-0.02 ± 0.03	-0.01 ± 0.04	-0.05 ± 0.05	-0.05 ± 0.05
14	Maternal education[8]	0 ± 0.02	0 ± 0.02	-0.01 ± 0.02	0.03 ± 0.03	0.02 ± 0.03	-0.02 ± 0.03	0 ± 0.04	-0.03 ± 0.05	-0.03 ± 0.05
15	Wealth index	0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.03	0.04 ± 0.03	0.03 ± 0.03	0 ± 0.03	0.04 ± 0.04	0.02 ± 0.05	0.04 ± 0.05
16	Season	0.02 ± 0.02	0.03 ± 0.02	0.02 ± 0.03	0.04 ± 0.03	0.03 ± 0.03	0 ± 0.03	0.04 ± 0.04	0.02 ± 0.05	0.03 ± 0.05

Abbreviation: MUAC, mid-upper arm circumference; HC, head circumference; CC, chest circumference; BMI: body mass index, calculated as weight (kg)/[length(m)^2]; GA, gestational age; WDDS, women's dietary diversity score; BF, breastfeeding; CF, complementary feeding;

1. Values are mean ± SE. Bold numbers are significant at 0.05 level.
2. Birth length is adjusted for the hour interval of measurement since delivery
3. Ponderal index is calculated as birth weight (kg)/length(m)^3
4. Breast feeding practices adjusted include frequency of breastfeeding and whether the baby was reported being fed with enough breast milk from the previous day.
5. Complementary feeding practices adjusted are the ones have significant differences across the HFI groups in table 1, including whether or not in the past 7 days infant was fed with formula, milk (powdered or fresh), dairy, dal, banana and other food and whether or not added oil or sugar.
6. Child morbidity adjusted includes whether or not infant had morbidity symptoms of acute respiratory, diarrhea, dysentery and fever in the previous 7 days.
7. Maternal employment is whether or not mother had a paid job at enrollment.
8. Maternal education is the highest women have completed.

Table 7.4: Odds ratio of infant malnutrition at 6 month of age comparing infants from food insecure households with infants from food-secure households (reference group)[1]

Model index	Variable added	Wasting (WLZ<-2)		
		Mild	Moderate	Severe
1	HFI (unadjusted)	1.13 (0.96, 1.33)	1.11 (0.92, 1.33)	**1.36 (1.14, 1.61)**
2	Parity+ maternal age +maternal GA	1.12 (0.95, 1.33)	1.09 (0.91, 1.31)	**1.30 (1.09, 1.55)**
3	Maternal height	1.11 (0.94, 1.32)	1.08 (0.90, 1.29)	**1.27 (1.06, 1.52)**
4	Maternal MUAC	1.08 (0.92, 1.28)	1.02 (0.85, 1.23)	1.17 (0.97, 1.40)
5	WDDS	1.08 (0.91, 1.27)	1.01 (0.84, 1.22)	1.15 (0.96, 1.38)
6	Infant's GA at birth	1.08 (0.91, 1.27)	1.01 (0.84, 1.22)	1.15 (0.96, 1.39)
7	Birth length[2]	1.07 (0.91, 1.27)	1.00 (0.83, 1.21)	1.15 (0.95, 1.38)
8	Ponderal index[3]	1.05 (0.88, 1.24)	0.96 (0.79, 1.16)	1.09 (0.91, 1.32)
9	BF practices[4]	1.03 (0.87, 1.22)	0.93 (0.77, 1.12)	1.02 (0.85, 1.24)
10	CF practices[5]	1.04 (0.88, 1.24)	0.94 (0.78, 1.14)	1.05 (0.87, 1.26)
11	Child morbidity[6]	1.04 (0.88, 1.23)	0.94 (0.78, 1.14)	1.03 (0.86, 1.25)
12	Maternal employment[7]	1.04 (0.88, 1.23)	0.94 (0.77, 1.13)	1.03 (0.85, 1.24)
13	Maternal education[8]	1.04 (0.87, 1.23)	0.93 (0.77, 1.13)	1.02 (0.84, 1.24)
14	Wealth index	1.00 (0.84, 1.19)	0.88 (0.73, 1.08)	0.96 (0.78, 1.17)
15	Season	0.99 (0.83, 1.18)	0.88 (0.72, 1.07)	0.95 (0.78, 1.16)

(Table 7.4 Cont'd)

Model index	Variable added	Stunting (LAZ<-2)		
		Mild	Moderate	Severe
1	Unadjusted	1.06 (0.96, 1.18)	**1.27 (1.13, 1.42)**	**1.39 (1.24, 1.55)**
2	Parity+ maternal age +maternal GA	1.05 (0.94, 1.16)	**1.24 (1.11, 1.39)**	**1.39 (1.24, 1.56)**
3	Maternal height	0.98 (0.88, 1.09)	1.12 (1.00, 1.26)	**1.20 (1.07, 1.36)**
4	Maternal MUAC	0.97 (0.86, 1.08)	1.10 (0.97, 1.23)	**1.16 (1.03, 1.31)**
5	WDDS	0.96 (0.86, 1.07)	1.08 (0.96, 1.22)	**1.14 (1.00, 1.28)**
6	Infant's GA at birth	0.95 (0.85, 1.06)	1.08 (0.96, 1.22)	1.12 (0.99, 1.27)
7	Birth length[2]	0.92 (0.81, 1.04)	1.03 (0.90, 1.18)	1.07 (0.93, 1.23)
8	Ponderal index[3]	0.92 (0.81, 1.04)	1.02 (0.90, 1.17)	1.06 (0.93, 1.22)
9	BF practices[4]	0.91 (0.80, 1.03)	1.01 (0.88, 1.16)	1.03 (0.90, 1.18)
10	CF practices[5]	0.91 (0.80, 1.03)	1.02 (0.89, 1.17)	1.05 (0.91, 1.20)
11	Child morbidity[6]	0.91 (0.80, 1.03)	1.02 (0.89, 1.17)	1.04 (0.90, 1.20)
12	Maternal employment[7]	0.91 (0.80, 1.03)	1.02 (0.89, 1.17)	1.04 (0.90, 1.19)
13	Maternal education[8]	0.90 (0.79, 1.02)	0.99 (0.86, 1.14)	1.01 (0.87, 1.16)
14	Wealth index	**0.87 (0.77, 0.99)**	0.96 (0.83, 1.11)	0.97 (0.83, 1.12)
15	Season	**0.87 (0.76, 0.99)**	0.95 (0.82, 1.10)	0.96 (0.82, 1.11)

(Table 7.4 Cont'd)

Model index	Variable added	Underweight (WAZ<-2)		
		Mild	Moderate	Severe
1	Unadjusted	**1.18 (1.06, 1.31)**	**1.37 (1.22, 1.54)**	**1.62 (1.44, 1.81)**
2	Parity+ maternal age +maternal GA	**1.16 (1.04, 1.29)**	**1.34 (1.20, 1.51)**	**1.58 (1.41, 1.77)**
3	Maternal height	1.11 (0.99, 1.24)	**1.25 (1.11, 1.40)**	**1.42 (1.26, 1.60)**
4	Maternal MUAC	1.08 (0.97, 1.21)	**1.19 (1.06, 1.34)**	**1.32 (1.17, 1.49)**
5	WDDS	1.07 (0.96, 1.20)	**1.17 (1.04, 1.32)**	**1.29 (1.14, 1.46)**
6	Infant's GA at birth	1.06 (0.95, 1.19)	**1.17 (1.04, 1.32)**	**1.28 (1.13, 1.45)**
7	Birth length[2]	1.06 (0.94, 1.19)	**1.14 (1.01, 1.30)**	**1.26 (1.11, 1.44)**
8	Ponderal index[3]	1.05 (0.93, 1.18)	1.11 (0.98, 1.27)	**1.22 (1.07, 1.40)**
9	BF practices[4]	1.02 (0.91, 1.16)	1.08 (0.95, 1.23)	**1.15 (1.00, 1.31)**
10	CF practices[5]	1.03 (0.91, 1.17)	1.10 (0.96, 1.25)	**1.17 (1.02, 1.33)**
11	Child morbidity[6]	1.03 (0.91, 1.16)	1.09 (0.95, 1.24)	**1.15 (1.00, 1.32)**
12	Maternal employment[7]	1.03 (0.91, 1.16)	1.08 (0.95, 1.24)	**1.15 (1.00, 1.31)**
13	Maternal education[8]	1.02 (0.90, 1.15)	1.06 (0.93, 1.22)	1.12 (0.97, 1.28)
14	Wealth index	0.99 (0.87, 1.12)	1.02 (0.89, 1.18)	1.06 (0.92, 1.23)
15	Season	0.99 (0.87, 1.12)	1.02 (0.88, 1.17)	1.07 (0.92, 1.23)

Abbreviation: WLZ, weight-for-length Z-score; LAZ, length-for-age Z-score; WAZ, weight-for-age Z-score; MUAC, mid-upper arm circumference; WDDS, women's dietary diversity score; GA, gestational age; BF, breastfeeding; CF, complementary feeding;

1. Values are OR (95%CI). Bold numbers are significant at 0.05 level.
2. Birth length is adjusted for the hour interval of measurement since delivery
3. Ponderal index is calculated as birth weight (kg)/length(m)^3
4. Breast feeding practices adjusted include frequency of breastfeeding and whether the baby was reported being fed with enough breast milk from the previous day.
5. Complementary feeding practices adjusted are the ones have significant differences across the HFI groups in table 1, including whether or not in the past 7 days infant was fed with formula, milk (powdered or fresh), dairy, dal, banana and other food and whether or not added oil or sugar.
6. Child morbidity adjusted includes whether or not infant had morbidity symptoms of acute respiratory, diarrhea, dysentery and fever in the previous 7 days.
7. Maternal employment is whether or not mother had a paid job at enrollment.
8. Maternal education is the highest women have completed.

CHAPTER 8: Summary and Conclusions

Introduction

Food insecurity is an entrenched problem in South Asia, where an estimated 300 million or more people are thought affected, accounting for over a one-third of all undernourished people in the world (1). Bangladesh bears the highest burden of maternal undernutrition and early childhood stunting globally, with 28% of all women and 43% of all children under five years of age affected, according to the Demographic Health Surveys. Accumulated evidence has linked household food insecurity (HFI) in poor settings with maternal malnutrition (2, 3) and increased risks of early childhood stunting and underweight (4-7). Only few studies conducted in developed countries (8, 9) have studied how maternal nutrition during pregnancy and lactation responds to HFI. Because most previous studies in low-income countries have been cross-sectional, the dynamics and influences of HFI on maternal and infant nutritional outcomes, from conception to the postnatal period, remains largely unknown.

Using prospective dietary and nutrition data from a large cluster-randomized prenatal supplementation trial, this dissertation explored the association between HFI and 1) maternal antenatal and postpartum dietary quality; 2) changes in maternal ponderal status during pregnancy and lactation; and 3) infant growth at 6 month of age. In this chapter, key findings from the dissertation are first presented and discussed, followed by implications, future research opportunities and finally enclosed by overall conclusion.

Key Findings

HFI in rural Bangladesh is prevalent and likely to be chronic.

Among 16, 996 households with complete data on the responses to Food Access Survey Tool (FAST), 50% have reported any degree of food insecurity. The prevalence is in line with the US Agency for International Development reported estimates of rural impoverished in Bangladesh (10): 44% are living under poverty line and facing food insecurity. The prevalence identified by FAST in our study area is within the range of 30-70% reported prevalence of HFI by recent studies (4, 11) or survey reports (2, 10) that applied similar behavior-based scales in rural Bangladesh.

Our cross-sectional HFI assessed at 6 mo postpartum is strongly associated with smaller maternal stature, an indicator of chronic nutritional status, higher risk of maternal undernutrition at early pregnancy, and poorer maternal diet from early pregnancy throughout lactation, indicating a relative static food insecurity condition in rural Bangladesh that was previously observed (12). Nearly half (47%) of the households followed at 1-2 years later from the initial food insecurity assessment have unchanged responses to a subset of the food insecurity scale. No strong evidence has supported substantial change in household long-term livelihood or wealth, which predicts HFI in poor rural settings (13). The abovementioned findings add confidence of using the cross-sectional food insecurity as a valid proxy for long-term food insecurity in rural Bangladesh.

Maternal dietary quality is lower in a dose-response way by HFI from early pregnancy to early lactation in rural Bangladesh.

Using prospective dietary data of 14,600 women at 1st and 3rd trimester of pregnancy and at 3 mo postpartum, we identified women's dietary diversity, represented by their dietary diversity score of 10 food groups, decrease progressively with poorer household food security, mostly driven by reduced consumption of animal-source foods. In addition, food insecure women were more likely to consuming certain plant-based foods, such as legumes and nuts and dark green leafy vegetables. Under economic stress to acquire food, food insecure households are likely choosing more affordable staple or plant-source foods over more nutritious animal-source foods (14-16). The inverse correlation between HFI and dietary quality were observed previously among non-pregnant non-lactating women (17, 18). Under HFI, poorer maternal dietary intakes persist from gestation to early lactation, indicating higher risk of micronutrient deficiency among women living under food insufficient households in rural Bangladesh (19-22).

HFI is associated with smaller maternal size at early pregnancy, which determines the trajectory of gestational and postpartum change in maternal ponderal status.

Based on the inclusion and exclusion criteria on birth outcome (term live singleton birth) and assessment window (see Chapter 6), a total number of 7,338 women were included in the dissertation to study the influence of HFI on dynamic change in maternal sizes from 1st to 3rd trimester in pregnancy and from 1st mo to 3rd mo postpartum in lactation. Maternal height and body mass index (BMI) at early onset of pregnancy was negatively associated with the severity of HFI, from 150.4 cm and 19.4 kg/m^2 in food secure group to 148.9 cm and 18.7 kg/m^2 in the severe HFI group. HFI did not modify the rate of change in weight or mid-upper arm circumference (MUAC), nor was HFI associated with the absolute size change during pregnancy or early lactation. After accounting for seasonality, maternal demographic and household socioeconomic factors, per one unit increase in maternal BMI in 1st trimester was associated with 370 g less in gestational weight gain and 0.17 cm less in MUAC change from 1st to 3rd trimester; for every one additional kilogram gained in pregnancy, women lost 120-130 g more in weight and 0.04-0.06 cm in MUAC in lactation from 1 to 3 mo postpartum. Variability in gestational and postpartum nutritional status was also observed previously (23, 24). More than 90% of the observed variability was attributable to maternal nutritional status in first trimester, which was negatively associated with HFI status and determined the trajectory of maternal weight and MUAC change in pregnancy and lactation.

Mid-infancy undernutrition was strongly associated with HFI, mostly mediated by maternal nutritional stressed during pregnancy rather than postnatal infant diet and morbidity.

Data from 12,693 mother-infant dyads were used to examine the plausible pathways by which HFI influenced child growth during in first half of infancy. Infant weight, length, circumferences in arms, chests and heads all shared a negative dose-response relationship with the severity of HFI. The unadjusted association was mostly explained by maternal nutrition at early pregnancy and birth size, by 39-67% and 11-33%, respectively. Together maternal nutrition and birth sizes explained 57-89% of the size deficits found in unadjusted models. Postnatal feeding and infant morbidity accounted for less than a third variability in infant size at 6 month of age. Risk of infant wasting, stunting, and underweight increased progressively with the intensity of HFI and gradually attenuated after maternal nutrition, birth size, and postnatal and contextual factors were adjusted. The association between HFI and early infant growth was mostly mediated by maternal nutrition during pregnancy. In other resource-poor settings (4, 6, 7, 25), positive relationship between HFI and child growth deficit was also observed except in two studies conducted in Nepal (26) and Sri Lanka (27). The Nepali study included a wealth index in the analysis, which was a composite index for overall household entitlement ownership. It was unlikely to examine the association between HFI and child growth by simultaneously adjusting for an contextual socio-economic status in the model, which was a strong predictor of HFI (figure 2.4) and child malnutrition (28). The Sri Lankan study adjusted additional nutritional factors such as maternal height and birth weight, feeding practices, and complementary food consumed in the multivariate analysis, which had presented a mediating pathway through which chronic HFI exert impact on postnatal growth. This dissertation seeks to identify and quantify proximal determinants of this long-term pathway linking HFI and infant size. By applying cumulative adjustment approaches, we are able to partition the impact of prenatal and postnatal factors and to reveal the window in which and causal pathways by which infant growth faltering occurs.

Implications

HFI persists in poor rural South Asian households. A simple behavior-based food insecurity scale with relatively long recall period is of use to quickly screen households at risk of chronic food insecurity (29-31). Women living under chronic HFI consume poorer diet and are at higher risk of being undernutrition compared with food secure women. The nutrition deficits in mothers from long-term food deprivation are evident from early pregnancy to early lactation and continued to restrict postnatal growth in their offspring. Chronic HFI exerts negative impact on maternal and early infant nutritional status mainly through a materno-feto-infant pathway. The timing of interventions in terms of addressing HFI and maternal and child malnutrition should be focused on women of reproductive age before and during pregnancy. Findings from this dissertation reinforced the importance of sustainable programming efforts and agricultural, nutrition and economic policy development to correct, not transit, but chronic HFI in South Asia, where a third of the global burden of undernutrition resides.

Strengths and Limitations

Using prospective data from a materno-infant cohort, this dissertation was able to investigate the dynamic relationship between HFI, assessed by a behavior based scale, and maternal and infant nutritional outcomes. To our knowledge, this was the first study examining HFI and its relation to longitudinal food utilization within mother-infant dyads in rural Bangladesh. The large sample size increased the power of this study and enabled building sophisticated statistical models with adjustments on a wide range of covariates. Models were comprehensively controlled for confounding factors because two level of covariates were collected in the trial: a) at maternal level, predictors for energy and nutrient metabolism and utilization were included, such as age, parity, breastfeeding practices, heavy physical activity, proceeding pregnancy outcome and space with the current pregnancy, etc; and b) at household level, predictors for household food availability and allocation were involved, such as household size, religion, maternal education, and wealth index, etc. Because of a variety of nutritional outcomes were collected in mothers and in infants, we were able to explore the relationship of the exposure of interest with a range of nutritional outcomes, which reflected different aspects of maternal and child nutritional status. This dissertation also has couple contributions in terms of methodologies in HFI assessment. Using empirical data and graded response modeling approaches, the validity of using a summative index of the Likert scale FAST was first established. With HFI data collected from a follow-up survey, this dissertation was able to compare longitudinal assessments on HFI and socio-economic status over a period of 1-2 years in our study area. Also, sensitivity analyses in this dissertation provided evidences of the robustness of the results from this study.

This dissertation also has limitations. First, the earliest available data on a 6-month history of HFI was collected only once at 6 month postpartum, yet nutritional outcomes of interested occurred between early pregnancy to mid-infancy. The temporal association between exposure and outcomes was based on the assumption of a stable and unchanged food security status. This limitation was not uncommon in the HFI literature, where only one HFI assessment was available (4, 27, 32). However, it is likely to be a valid assumption in this rural South Asian setting supported by the findings from this dissertation. Data from the tri-annual food insecurity surveillance in Bangladesh, assessed by a similar behavior-based scale HFAIS with one-month recall period, suggested seasonal fluctuation in the perceived HFI (10). The recall period of 6 months in our scale did not fully represent a year-round food security status. In this dissertation, the season in which HFI was assessed was controlled for all three aims. Therefore, results from adjusted models should be able to compare HFI strata controlling for any seasonal variation in scale responses. Secondly, as expected in prospective cohorts, loss-to-follow up could induce potential bias. For example, infant mortality, which was found more likely in household with reported food insecurity (33), could result in survival bias, which led to an underestimation of the estimated odds ratios of infant malnutrition comparing infants from food insecure households with the infants from food secure households. There were other types of loss-to-follow up that could potentially influence the validity of research findings yet the direction of bias was hard to predict given limited information. Because of the small proportion of loss-to-follow up in this study, it was expected that the bias introduced by losses should not be substantial. The third limitation is the potential bias introduced by missing data which could either attenuate or inflate the relationship between HFI and outcomes of interest. The comparison on selected characteristics between included and excluded households was done for each individual paper (**Appendix 5.4, 6.6, 7.6**). Comparing with included households, the excluded households were slightly poorer in the first aim but tend to be wealthier in the second and third aim. Imputation could have been done to replace missing values by employing valid modeling schemes. Overall, our study area represents average to below-average socio-economic context. The external validity of this study may be more applicable to poorer households in rural South Asia, where food insecurity remains as a concern.

Future Research Opportunities

This dissertation hypothesized an unchanged relative rank of chronic HFI over lean and harvest season (Appendix 6.5). Future studies should include repeated assessments on HFI status to examine how households' long-term HFI status change over time. Given the strong mediation effect of maternal nutrition on the association between HFI and infant growth, additional research focusing on the relationship between HFI and the growth under five should be aware of the materno-feto nutritional mechanism and should incorporate the nutritional pathway in the analysis. Conditioning on infant growth deficit at 6 month, which is mostly driven by HFI through maternal undernutrition, it would be of important programming and policy's interest to understand how much growth faltering and child underweight in later postnatal growth could be directly addressed by improving food security versus other postnatal pathways.

Overall Conclusion

Household food insecurity is prevalent and persists in rural Bangladesh. In a large prospective pregnancy cohort, we found evidence supporting strong and persistent nutritional consequences of food insecurity reflected in poor maternal dietary quality, poor maternal nutritional status and infant growth faltering at 6 month of age. Policies that address both household food insecurity and reduce maternal and infant malnutrition should focus in women early in, and likely long before, pregnancy.

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APPENDICES

Appendix 1: JiVitA Cohort Update Form (JCUF)

JiVitA-JCU / Form 001, JCUF, v.1.0, January 25, 2012

JiVitA Cohorts Update Form (JCUF)

Worker ID: ☐☐☐☐ ______ Initials

Section A: Identifiers **Date of Interview:** ☐☐ / ☐☐ JiVitA Week: ☐☐☐

AC Area: ☐☐ TL PIN: ☐☐ Sector: ☐☐☐ Mauza: ______

	Age (Yrs)	Consent	Vital Status	MUAC (cm)
☐☐☐☐☐☐ Woman UID; ______ Woman Name; Preg: ☐ *0=No 1=Yes 9=Don't know* LMP ☐☐/☐☐/☐☐ *d d m m y y*	☐☐	1. ☐ *0=Refused 1=Yes 2=Not met 3=Interview with family members 7=PM*	☐	☐☐.☐ *66.6= Refused 99.9=Not measured*
☐☐☐☐ HH; ______ Husband Name; If re-married due to husband died or divorced ______ Current Husband Name		2. ☐ *0=Refused 1=Yes*	☐ *1=Alive 8=Dead, 9=Don't know*	
		Child Assent		
☐☐☐☐☐☐ Child 1 UID; ______ Child Name; Sex ☐ *1=Male 2=Female 9=DK*	☐☐	☐	☐	☐☐.☐ *66.6= Refused 99.9=Not measured*
☐☐☐☐☐☐ Child 2 UID; ______ Child Name; Sex ☐	☐☐	☐ *0=Refused 1=Yes 2=Not met 5=Adopted*	☐	☐☐.☐

Section B: Timing and Cause of Death

Complete this section, if vital status code is '8' in Section A

	Date of Death *m m / y y*	Did [WOMAN NAME] die during pregnancy or within 6 weeks of the pregnancy outcome? *0=No 1=Yes 9=Don't know*	Did [NAME] die of an injury or accident? *0=No 1=Yes 9=Don't know*	How many days had ______ suffered from illness before he/she died? *1=Less than 3 months 2= 3 or more months 9=Don't know*
i. WOMAN	☐☐/☐☐	☐	☐	☐
ii. HUSBAND	☐☐/☐☐	X	☐	☐
iii. CHILD 1	☐☐/☐☐	X	☐	☐
iv. CHILD 2	☐☐/☐☐	X	☐	☐

Section C: Woman's Betel Nut and Tobacco Use *(Only fill up this section if code '1' is in consent box '1')*

1. How often do you usually chew betel nut/leaf? ☐
2. How often do you usually chew tobacco products like jarda, tamac, chutti, aluwa, sada, gul or khoiny? ☐

0=Never 1=Daily 2=Weekly but not daily 3=Monthly but not every week 4=Less than monthly

Page **1** of **2**

Section D: Household Information

1) How many members are there in your household?

☐ *1-7=Number*
8=8 or more
9=Don't know

2) How many almirahs/showcases does your HH own?

☐ *0=None*
1-7=Number
8=8 or more
9=Don't know

3) How many clocks (wall/wristwatch) does your HH own?

☐ *0=None*
1-7=Number
8=8 or more *9=Don't know*

4) How many cots /beds does your HH own?

☐ *0=None*
1-7=Number
8=8 or more *9=Don't know*

5) Number of living and sleeping rooms (Obs. and record):

☐ *0=None*
1-7=Number
8=8 or more *9=Don't know*

6) Construction of ground floor walls of the place the respondent lives (Obs.):

☐ *0=No walls (<2 walls or 3 polythene walls)*
1=Grass (reeds, straws, jute sticks)
2=Bamboo, betel nut plants, earth
3=Tin/Wood plank
4=Cement and brick *9=Don't know*

7) Does your household have at least one working mobile phone?

☐ *0=No*
1=Yes *9=Don't know*

8) During the past 3months, have you or any member of your household used a mobile phone for emergency health purposes? (Medical advices, call a provider, arrange transport or ask for financial support)

☐ *0=No*
1=Yes *9=Don't know*

9) Does your house have electricity?

☐ *0=No*
1=Government electricity supply (PDB, Rural Electrification Board)
2=Generator
3=Solar power
8=Other *9=Don't know*

10) In the past year, how many types of vegetables were grown by your household?

☐ *0=None*
1-7=Number
8=8 or more *9=Don't know*

11) In the past year, how many types of fruits have you grown?

☐ *0=None*
1-7=Number
8=8 or more *9=Don't know*

12) How many mature chickens/ducks does your household have?

☐ *0=None*
1-7=Number
8=8 or more

13) H13. How many goats / sheep does your household have?

0=None
☐ *1-7=Number*
8=8 or more *9=Don't know*

14) How many cows/buffalos does your household have?

☐ *0=None*
1-7=Number
8=8 or more *9=Don't know*

15) Does your household own a fishpond?

☐ *0=No*
1=Yes *9=Don't know*

16) Does water of the tubewell you drink, contain no iron, a little, a medium amount, or a lot of iron?

☐ *0=None*
1=A little
2=A medium amount
3= A lot
4=Don't drink tubewell water
9=Don't know

17) In the past 6 months, how often did your family purchase rice?

☐ *0=Never*
1=Rarely (1-3 times)
2=Sometimes (4-6 times)
3=Often (a few times each month)
4=Mostly (most days per week)
9=Don't know

18) In the past 6 months, how often did you worry about where food would come from?

☐ *0=Never*
1= Rarely (1-3 times)
2= Sometimes (4-6 times)
3=Often (a few times each month)
4=Mostly (most days per week)
9=Don't know

19) In the past 30 days, was there ever no food at all in your household because there were no resources to get more? (i.e. no food grown, no money to buy food, or nothing to exchange food for)

☐ *0=No*
1=Rarely (1-2 times)
2=Sometimes (3-10times)
3=Often (more than 10 times)
9=Don't know

20) In the past 30 days, did you or any household member go to sleep at night hungry because there was not enough food?

☐ *0=No*
1=Rarely (1-2 times)
2=Sometimes (3-10times)
3=Often (more than 10 times)
9=Don't know

21) In the past 30 days, did you or any household member go a whole day and night without eating because there was not enough food?

☐ *0=No*
1=Rarely (1-2 times)
2=Sometimes (3-10times)
3=Often (more than 10 times)
9=Don't know

Appendix 2: Approval of JCUS from the Bangladesh Medical Research Council

বাংলাদেশ চিকিৎসা গবেষণা পরিষদ
Bangladesh Medical Research Council

BMRC

Ref: BMRC/NREC/2010-2013/1897 Date: 12.12.2011

Keith P. West
Johns Hopkins Principal Investigator, JiVitA
Director, Center and program in Human Nutrition
Deptt. of International Health, Suite W 2041
Johns Hopkins Bloomberg School of Public Health
615 North Wolfe Street
Baltimore, Maryland 21205 USA

Subject: Regarding amendment of project entitled "Antenatal Multiple Micronutrient Supplementation to Improve Maternal and Infant Health and Survival in Bangladesh: A Two-Arm Cluster Randomized Controlled Trial"

Research proposal entitled **"Antenatal Multiple Micronutrient Supplementation to Improve Maternal and Infant Health and Survival in Bangladesh: A Two-Arm Cluster Randomized Controlled Trial"** was submitted for ethical approval in 5th December, 2006. Ethical approval was communicated to you on 3rd December, 2007 (Ref: BMRC/ERC/2007-2010/935 dated 03.12.2007). You have applied for amendment of the above proposal on 30th October, 2011.

After due consideration ethical approval of the above mentioned ongoing research proposal has been granted.

Thanking you

Millat

(Professor Dr. Md. Habibe Millat)
Honorary Director

BMRC Bhaban, Mohakhali, Dhaka-1212, Bangladesh
Phone: +88 02 8828396, PABX +88 02 8819311, Fax: +88 02-8828820; E-mail: info@bmrcbd.org, Web: www.bmrcbd.org

Appendix 3: Approval of JCUS from the JHSPH Institutional Review Board

JOHNS HOPKINS BLOOMBERG SCHOOL *of* PUBLIC HEALTH

FWA #00000287

Institutional Review Board Office

615 N. Wolfe Street / Suite E1100
Baltimore, Maryland 21205
Office Phone: (410) 955-3193
Toll Free: 1-888-262-3242
Fax Number: (410) 502-0584
E-mail Address: irboffice@jhsph.edu
Website: www.jhsph.edu/irb

INITIAL APPLICATION APPROVAL NOTICE

Date: January 17, 2012

To: Keith West, DrPH
Department of International Health

From: Elizabeth A. Skinner, MSW
Chair, IRB-X

Re: **Study Title**: "Jivita Cohorts Update"
IRB No: 00003832

The **JHSPH IRB-X** voted to approve the above referenced application at its meeting on **September 29, 2011. The Board made the following determinations:**

Expedited ☐ **Convened** ☒ DHHS 46.110 ☒ DHHS ☐ FDA 56.110 ☐ FDA ☐ Category: 4 & 7 **GWAS** ☐	**Consent/Parental Permission Required From:** Adult Participant ☒ LAR ☐ One Parent ☒ Two Parents ☐ Legal Guardian ☐ (Foster Care Children)	**Form of Consent/Permission:** Written Consent ☐ Waiver of Signature ☒ (Oral Script) Waiver of Informed Consent ☐ HIPAA Authorization ☐ HIPAA Waiver ☐	**Study Site(s):** U.S. ☐ International ☒ **List Country(ies):** **Bangladesh**
Vulnerable Populations: **Children** ☒ **Foster Care Children** ☐ **DHHS** / **FDA** 46.404 ☒ 50.51 ☐ 46.405 ☐ 50.52 ☐ 46.406 ☐ 50.53 ☐	**Assent Required From:** No children (waived) ☐ Children aged: 7-9 ☒ **Form of Assent:** Written ☐ Oral ☒ Assent Statement in Parent Permission ☐	**Pregnant Women/Fetuses** 46.204 ☐ **Neonates** ☐ 46.205 **Prisoners** 46.305 ☐ 46.306 ☐ **Epidemiological Research** ☐	**Sample Size:** (screened plus enrolled) **Women=165,000** **Children=68,000** **Secondary Data Analysis**: (# specimens/participants)

Approval of the research is for the period of **September 29, 2011** to **September 28, 2012**. A Progress Report for continuing review must be submitted to the IRB Office no later than <u>six weeks</u> prior to the approval lapse date of **September 28, 2012.**

This approval is inclusive of the following documentation:

Research Plan (Version #2, 10-16-11)

Consent for Women or HH Members of Women Ever Enrolled-English and Bangladesh (Version #1, 9-29-11)

Parental Consent for Women or HH Members of Women Ever Enrolled-English and Bangladesh (Version #1, 9-29-11)

Child Assent for Children 6-10 Years Old English and Bangladesh (Version #1, 9-29-11)

JiVita Cohorts Update Form (Version #2, 10-6-11)

As principal investigator of the research, you are responsible for fulfilling the following requirements of approval:

1) The co-investigators listed on the application should be kept informed of the status of the research.
2) Submit an Amendment Request Form for any changes in research. These changes in research are required to be reviewed and approved prior to the activation of the changes, with the following exceptions:
    a) changes made to eliminate an apparent immediate hazard to the research participant may be instituted immediately and the JHSPH IRB should be informed of such changes promptly; and
    b) changes to IRB Approved questionnaires, interview or focus group guides, other data collection or recruitment materials – limited to rewording to clarify meaning, correcting grammatical or typographical errors, or removing items that will not be used in the research.
3) Unanticipated problems involving risk of harm to participants or others that are related to the study procedures must be reported to the JHSPH IRB within 10 days of the time that the PI learns of such problems**.** A Problem Event Report Form must be submitted to the IRB immediately.
4) Only consent forms with a valid JHSPH IRB approval stamp or logo, with the correct IRB Approved version number and approval date may be presented to participants. All consent forms signed by subjects enrolled in the study should be retained on file. The Office of Graduate Education and Research conducts periodic compliance monitoring of study records, and consent documentation is part of such monitoring.
5) Federal regulations require review of approved research not less than once a year, unless a shorter period is determined by the IRB. **Therefore, a Progress Report for continuing review must be submitted to the IRB Office no later than six weeks prior to the approval lapse date**. **This will allow sufficient time for review of the application to be completed prior to the approval lapse date**. Failure to submit a Progress Report prior to the approval lapse date will result in termination of the study, at which point new participants may not be enrolled and currently enrolled participants must discontinue participation in the study. All ongoing research activities must stop immediately, including data analysis.

6) If your research involves international travel, please don't forget to register with the International Travel Registry https://apps4.jhsph.edu/ITR/Default.aspx so that the School may locate you in the event of an emergency.

EAS/sro

Appendix 4: Approval of student investigator to the study team by JHSPH Institutional Review Board

JOHNS HOPKINS BLOOMBERG SCHOOL *of* PUBLIC HEALTH

FWA #00000287

JHSPH Institutional Review Board Office
Institutional Review Boards

615 N. Wolfe Street / Suite E1100
Baltimore, Maryland 21205
Office Phone: (410) 955-3193
Toll Free: 1-888-262-3242
Fax Number: (410) 502-0584
E-mail Address: irboffice@jhsph.edu
Website: www.jhsph.edu/irb

AMENDMENT APPROVAL NOTICE
EXPEDITED REVIEW

Date: October 4, 2012

To: Keith West, Dr.PH, and MPH
Department of International Health

From: Jonathan Links, Ph.D.
Chair, IRB-FC

Re: **Study Title**: "Antenatal Multiple Micronutrient Supplementation to Improve Infant Survival and Health in Bangladesh"
IRB No: 000000570

The JHSPH IRB received the amendment request described below on September 17, 2012. The IRB reviewed and approved this request on October 2, 2012**.**

This amendment approval is:

- To add Christopher Heaney as a co-investigator to the study team;
- To add Muzi Na and Youngji Jo as student investigators to the study team.

As a reminder, no other changes to this study may be implemented without prior JHSPH IRB review and approval.

The action taken on this study does not change the Exempt Determination date of **May 29, 2013**.

If you have any questions regarding this action, please contact the JHSPH IRB Office at (410) 955-3193 or via email at irboffice@jhsph.edu.

JL/rch

JHSPH IRB Amendment Approval – Expedited Review
Version #4, 3Mar10

Appendix Figures and Tables for Chapter 5

Appendix 5.1: Proportion of women reported any consumption of food groups by HFI groups[1]

		All	Food secure	Food insecurity		
				Mild	Moderate	Severe
Pregnancy average (PA)[2]	Vegetable oil	99.9	99.9	99.9	100.0	99.9
	Other FV	96.0	97.1	96.4	95.6	94.8
	Non-rice staple	89.1	91.2	90.4	88.5	86.4
	DGLV	69.8	72.0	68.8	69.8	68.9
	Legumes and nuts	51.4	57.2	51.6	49.8	46.8
	VAFV	30.4	35.8	31.5	28.2	25.9
	Fish	87.8	91.1	89.3	87.0	83.7
	Eggs	51.5	59.8	53.5	49.4	43.4
	Dairy	45.1	56.3	46.3	41.5	36.1
	Meat	42.4	50.5	45.3	39.8	33.9
	Organ meat	11.2	14.2	12.3	10.2	8.0
3 mo postpartum (3MP)	Vegetable oil	100.0	100.0	99.9	100.0	100.0
	Other FV	94.4	95.3	94.5	94.4	93.5
	Non-rice staple	92.2	94.6	93.3	92.1	88.6
	DGLV	54.8	56.3	53.4	53.4	56.1
	Legumes and nuts	40.0	46.5	40.9	36.5	36.0
	VAFV	21.9	26.9	21.9	20.7	18.0
	Fish	84.5	88.1	85.9	84.6	79.5
	Eggs	39.9	47.6	41.5	38.2	32.3
	Dairy	30.7	39.8	32.1	27.3	23.8
	Meat	40.0	47.8	41.6	38.9	31.7
	Organ meat	10.0	12.7	11.4	9.1	6.8
Diff(3MP-PA)	Vegetable oil	0.1	0.04	0.1	0.04	0.1
	Other FV	-1.5	-1.7	-1.9	-1.2	-1.3
	Non-rice staple	3.0	3.4	2.8	3.6	2.2
	DGLV	-15.0	-15.6	-15.3	-16.4	-12.8
	Legumes and nuts	-11.4	-10.7	-10.7	-13.3	-10.9
	VAFV	-8.5	-8.9	-9.6	-7.5	-7.9
	Fish	-3.2	-3.0	-3.4	-2.4	-4.1
	Eggs	-11.6	-12.2	-12.0	-11.2	-11.1
	Dairy	-14.3	-16.5	-14.2	-14.3	-12.3
	Meat	-2.4	-2.7	-3.7	-0.9	-2.2
	Organ meat	-1.1	-1.5	-0.8	-1.0	-1.1

Abbreviation: OR, odds ratio; DGLV, dark green leafy vegetables; VAFV, vitamin A-rich fruit and vegetables; Other FV, other fruit and vegetables.

1. Data presented is supplemental for figure 2

2. Pregnancy average proportion is calculated as the mean of the proportion reported at the 1st and 3rd trimester assessment.

Appendix 5.2: Median test, Kwallis test and the non-parametric test for linear trend on the non-zero frequency of food group consumption by HFI group[1]

	Median test		Kwallis test		Non-parameteric linear test	
	Chi-square	p-value	Chi-square adjusted for ties	p-value (adjusted)	Z	p-value
1st trimester						
Vegetable oil	206.5	***	313.1	***	-17.4	***
Other FV	54.9	***	80.9	***	-8.8	***
Non-rice staple	32.8	***	46.6	***	-6.2	***
DGLV	2.1	0.56	5.2	0.16	-2.0	*
Legumes and nuts	34.8	***	52.1	***	-7.1	***
VAFV	7.9	*	12.2	**	-3.0	**
Fish	104.3	***	131.6	***	-11.4	***
Eggs	94.2	***	133.4	***	-11.1	***
Dairy	183.4	***	198.7	***	-13.4	***
Meat	18.0	***	18.4	***	-4.2	***
Organ meat	5.2	0.16	5.6	0.13	-0.3	0.76
Meat & fish	163.7	***	240.1	***	-15.4	***
3rd trimester						
Vegetable oil	262.5	***	380.9	***	-19.4	***
Other FV	107.6	***	149.2	***	-12.1	***
Non-rice staple	27.4	***	44.4	***	-6.6	***
DGLV	2.4	0.50	4.9	0.18	-0.3	0.78
Legumes and nuts	40.8	***	54.4	***	-7.3	***
VAFV	7.0	0.07	5.1	0.16	-0.9	0.37
Fish	85.4	***	146.5	***	-11.9	***
Eggs	88.3	***	106.3	***	-10.2	***
Dairy	222.6	***	261.9	***	-16.0	***
Meat	36.9	***	66.5	***	-8.0	***
Organ meat	11.1	*	12.6	**	-3.2	**
Meat & fish	193.4	***	305.4	***	-17.4	***
3 mo postpartum						
Vegetable oil	245.3	***	458.0	***	-20.2	***
Other FV	22.0	***	38.7	***	-6.1	***
Non-rice staple	129.6	***	127.4	***	-11.2	***
DGLV	0.4	0.95	1.2	0.76	-0.7	0.51
Legumes and nuts	30.8	***	37.8	***	-5.8	***
VAFV	2.9	0.41	5.7	0.13	-2.1	*
Fish	94.8	***	128.1	***	-11.2	***
Eggs	66.8	***	84.3	***	-9.2	***
Dairy	150.1	***	198.2	***	-13.3	***
Meat	25.3	***	35.4	***	-5.4	***
Organ meat	11.2	*	11.3	*	-2.6	**
Meat & fish	170.6	***	244.5	***	-15.5	***

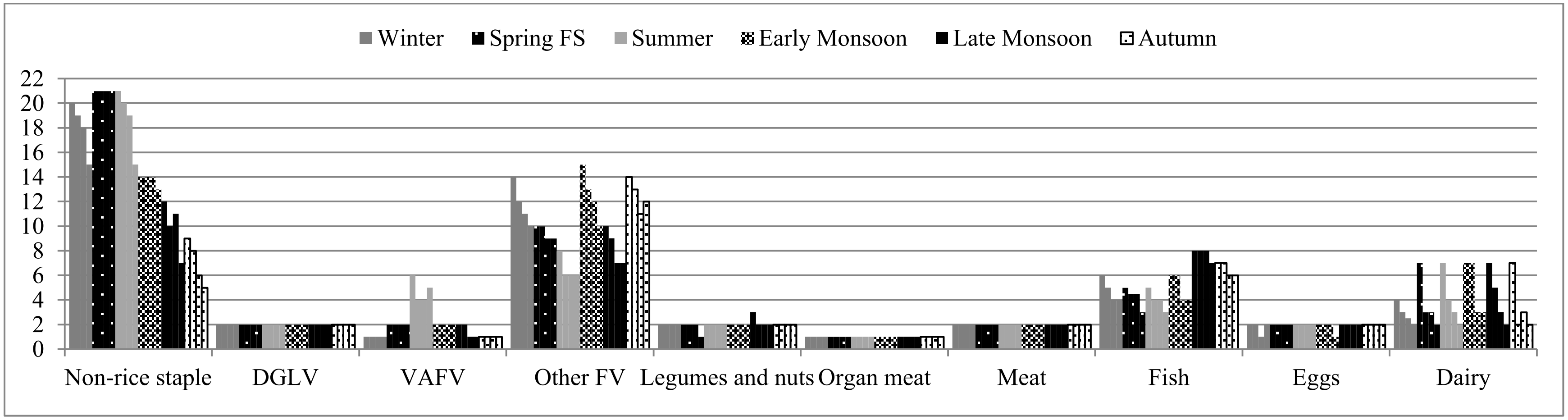
Abbreviation: OR, odds ratio; DGLV, dark green leafy vegetables; VAFV, vitamin A-rich fruit and vegetables; Other FV, other fruit and vegetables. P-values: *<0.05, **<0.01, ***<0.001.

1. Due to highly skewness of the frequency distribution, only non-parametric tests were selected that do not assume normality.

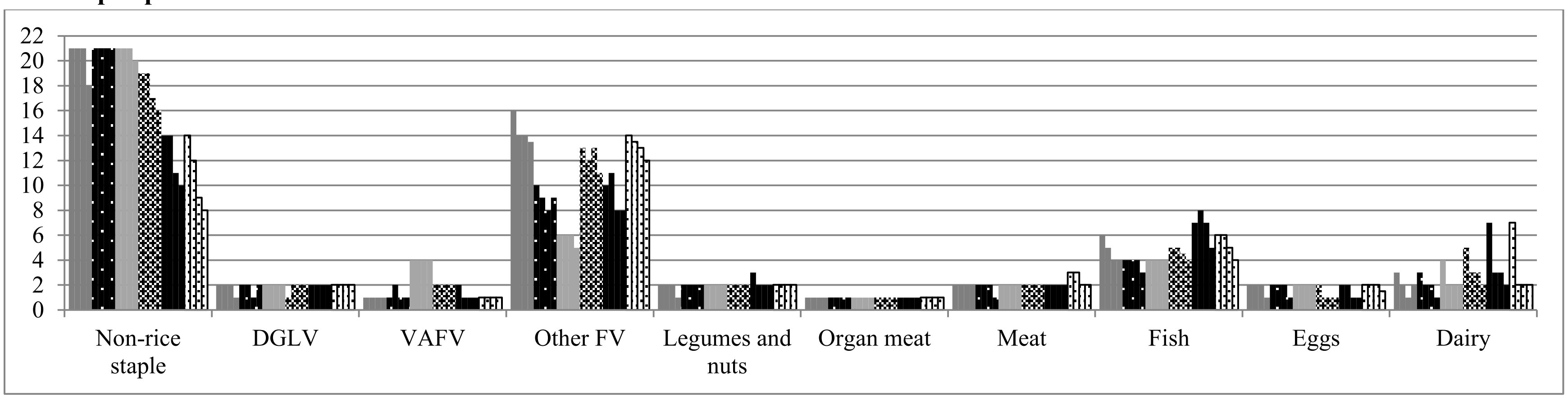
Appendix 5.3: Median frequency of food intake by season and by household food insecurity status

(Abbreviation: DGLV, dark green leafy vegetables; VAFV, vitamin A-rich fruit and vegetables; Other FV, other fruit and vegetables.)

A. 3rd Trimester



B. 3 mo postpartum



Appendix 5.4: Characteristics of included and excluded households in paper 1

	Included		Excluded		
	n	Mean ± SD or %	n	Mean ± SD or %	p-value[1]
Maternal characteristics					
GA at enrollment	14561	11.1 ± 5.0	4206	13.0 ± 7.3	***
Age, y	14600	22.9 ± 5.4	4257	22.2 ± 5.6	***
Parity	14600		4250		***
0		36.7		48.8	
1		34.8		27.9	
2		17.8		13.1	
≥3		10.8		10.2	
Socio-economic variables					
HFI score	14600	12.0 ± 4.7	2813	12.2 ± 4.9	**
Household size, n	14598	4.2 ± 2.0	4247	4.5 ± 2.2	***
Dependency ratio	14597	0.6 ± 0.4	4247	0.5 ± 0.4	***
Wealth index	14588	0.1 ± 1.0	4243	0.1 ± 1.1	0.50
HFI group	14600		2813		*
Food secure		50.3		48.5	
Mild HFI		20.1		19.8	
Moderate HFI		15.3		15.5	
Severe HFI		14.2		16.2	
Religion	14600		4249		*
Muslim		91.6		90.6	
Other		8.4		9.4	
Maternal employment	14599		4249		***
Had a paid job		40.8		30.7	
No paid job		59.2		69.3	
Maternal education	14592		4248		0.66
No education		23.6		24.0	
Primary or higher		76.4		76.0	
Wealth index tertile, %	14588		4243		***
Low		32.7		35.4	
Medium		34.2		30.5	
High		33.1		34.1	

Abbreviations: GA, gestational age; HFI, household food insecurity.

1. P-value is the ANOVA test for continuous variables or Chi-square test for categorical variables. ***, <0.001; **, <0.01; *, <0.5.

Appendix Figures and Tables for Chapter 6

Appendix 6.1: Change in nutritional status during pregnancy by household food insecurity status

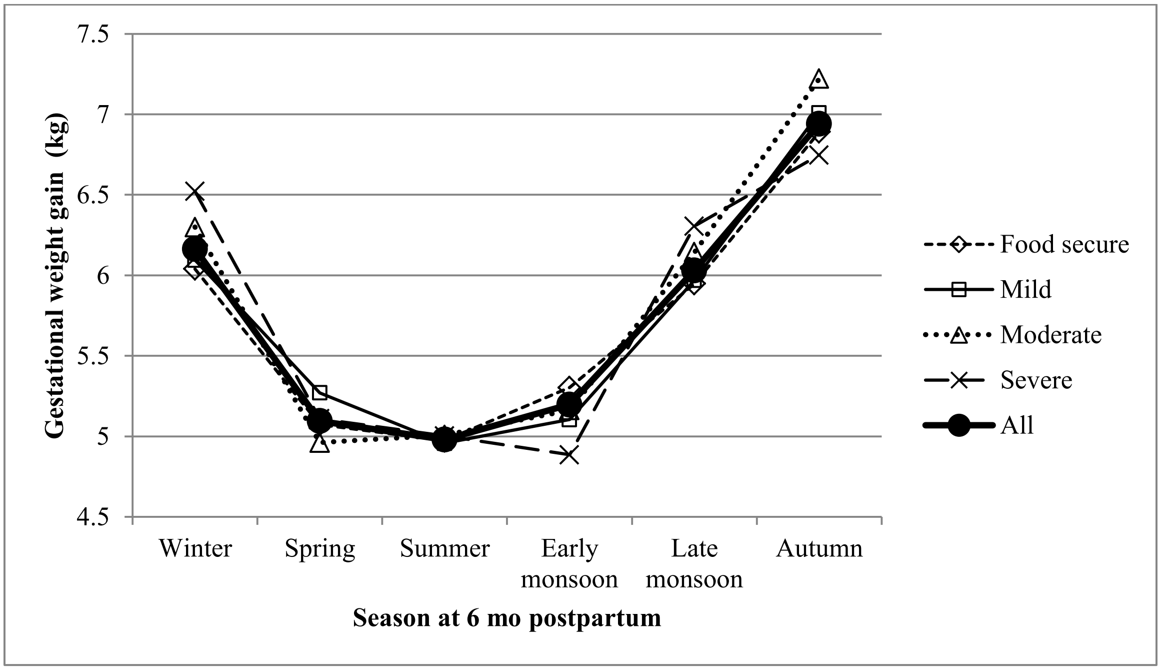
	Pregnancy		Lactation	
	Weight, kg	MUAC, cm	Weight, kg	MUAC, cm
Model results				
Intercept (β_{0ij}): Nutritional status at first assessment in food secure group[1]	43.90 (43.7, 44.1) ***	23.92 (23.85, 23.99) ***	44.96 (44.77, 45.15) ***	23.40 (23.33, 23.46) ***
Linear term (β_{1ij}): Change per week	0.24 (0.23, 0.24) ***	-0.01 (-0.012, -0.009) ***	-0.02 (-0.03, -0.02) ***	0.04 (0.03, 0.04) ***
Dummy coefficient (β_{2g}): Difference in nutritional status at 1TM				
Food secure (reference)	-	-	-	-
Mild	-0.80 (-1.18, -0.42) ***	-0.24 (-0.38, -0.11) **	-0.89 (-1.25, -0.53) ***	-0.27 (-0.40, -0.14) ***
Moderate	-1.50 (-1.90, -1.09) ***	-0.56 (-0.71, -0.41) ***	-1.47 (-1.86, -1.08) ***	-0.50 (-0.64, -0.36) ***
Severe	-2.42 (-2.84, -2.00) ***	-0.88 (-1.03, -0.72) ***	-2.18 (-2.59, -1.78) ***	-0.72 (-0.86, -0.58) ***
Interaction term (β_{3g}): Difference in status change rate				
Food secure (reference)	-	-	-	-
Mild	0.001 (-0.006, 0.008)	0.002 (-0.001, 0.005)	0.008 (-0.004, 0.019)	0 (-0.005, 0.005)
Moderate	0.004 (-0.003, 0.012)	0.003 (0, 0.006)	0.009 (-0.004, 0.022)	-0.001 (-0.007, 0.005)
Severe	0.007 (-0.001, 0.015)	0.006 (0.002, 0.009) **	0.006 (-0.007, 0.019)	-0.002 (-0.008, 0.004)
Variance structure				
Variance in initial status	35.34 (33.95, 36.78) ***	4.63 (4.42, 4.84) ***	34.66 (33.52, 35.85) ***	4.27 (4.12, 4.42) ***
Variance in status change rate	0.001 (-0.001, 0.008)	0.001 (0.0002, 0.001) **	0.02 (0.02, 0.03) ***	0.003 (0.002, 0.005) ***
Covariance between initial status and status change	-0.02 (-0.06, 0.01)	-0.02 (-0.03, -0.02) ***	-0.06 (-0.10, -0.03) ***	-0.01 (-0.02, -0.01) ***
Residual variance	3.14 (2.54, 3.89) ***	0.50 (0.39, 0.65) ***	0.62 (0.45, 0.85) ***	0.16 (0.12, 0.21) ***
% Variance in initial status	92%	90%	98%	96%

Abbreviation: 1TM, 1st trimester. *, <0.05; **, <0.01; ***, <0.001.

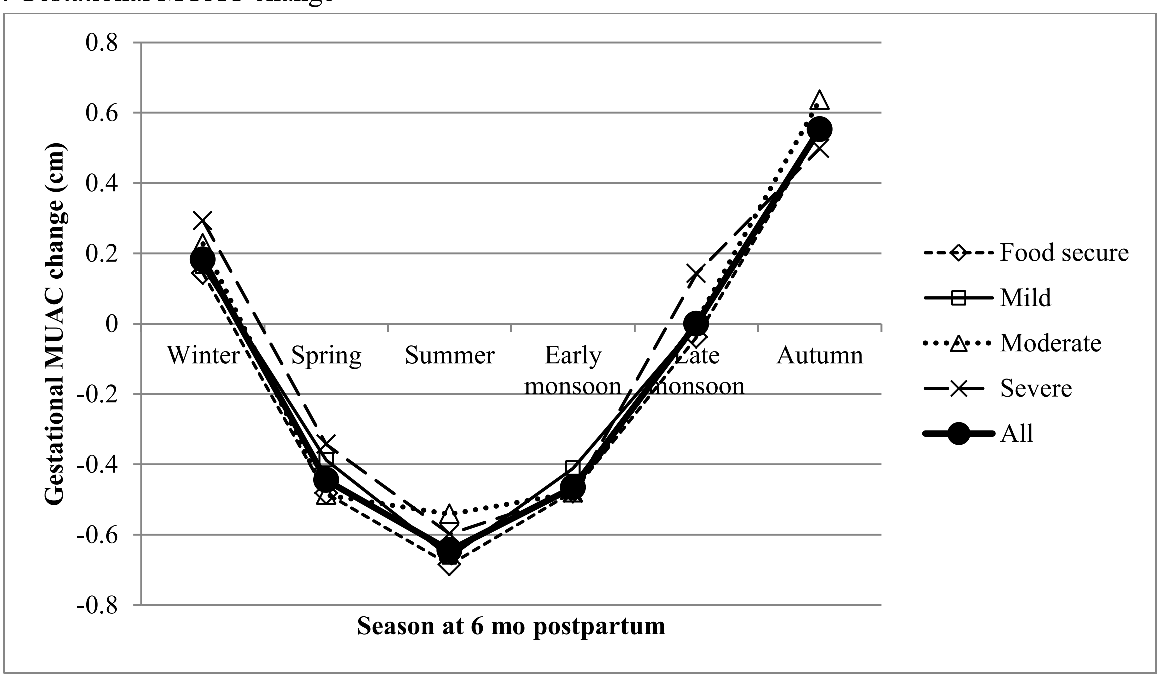
1. Centered at the mean week of gestational age during 1st trimester pregnancy or postpartum week during 1st mo postpartum

Appendix 6.2: Gestational weight gain (A) and MUAC change (B) from 1st trimester to 3rd trimester by season and by household food insecurity status

A. Gestational weight gain

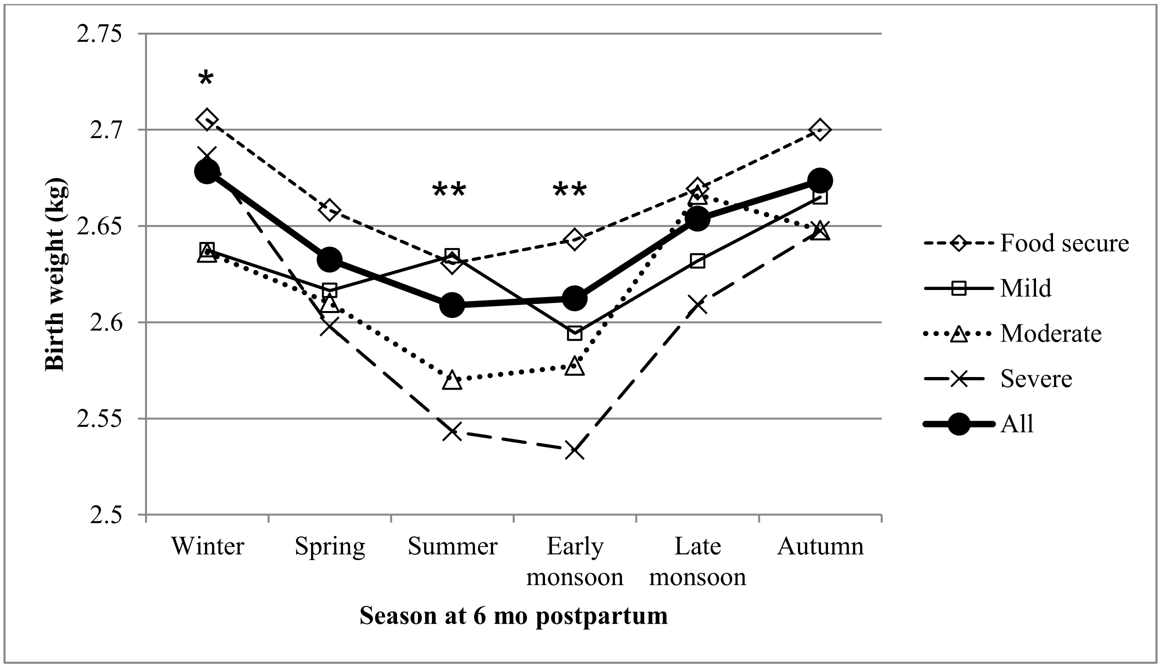


B. Gestational MUAC change



Note: In each season, the mean weight gain or MUAC change are not significant by HFI status (p>0.17)

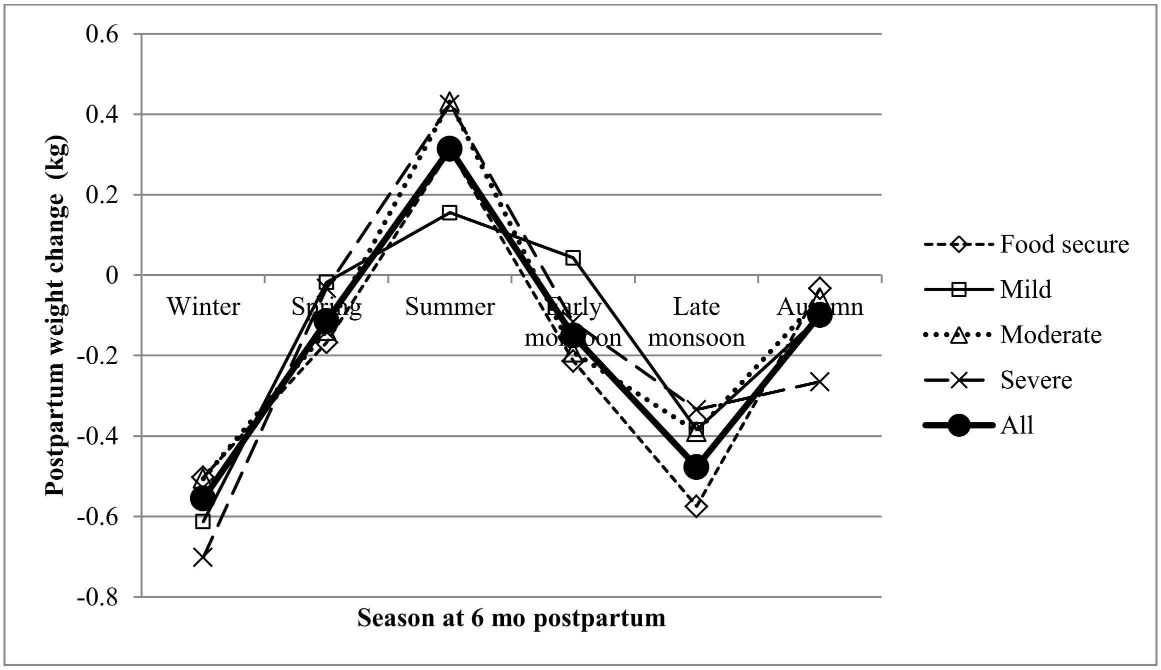
Appendix 6.3: Birth weight by season and by household food insecurity status



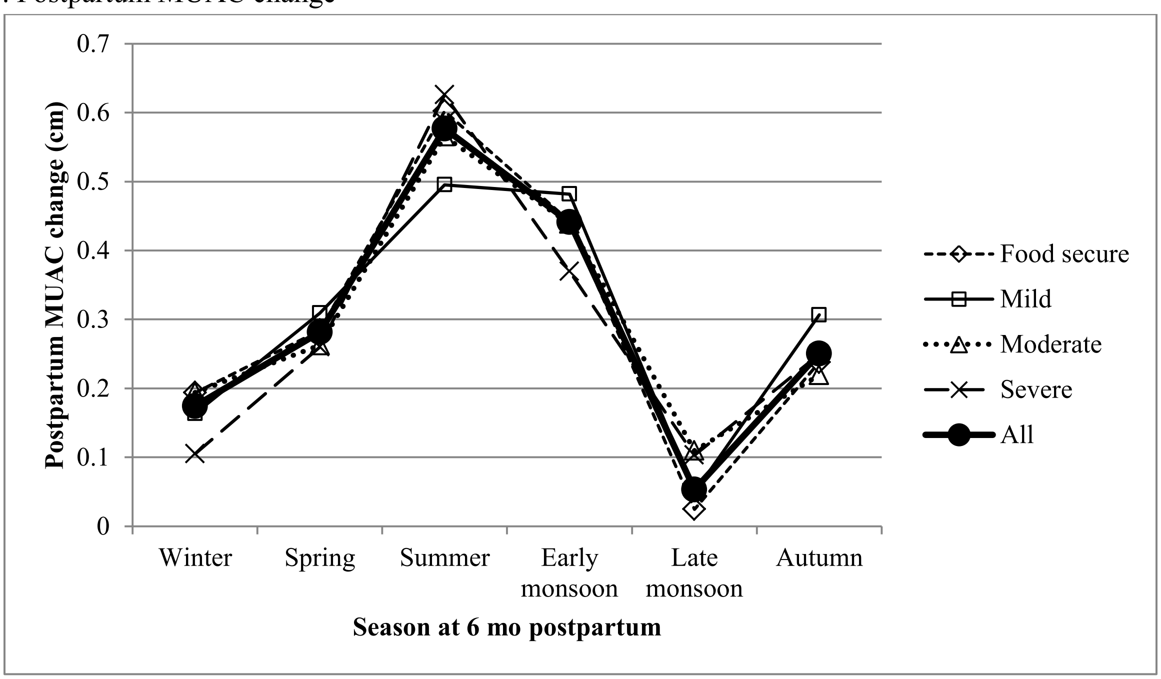
Note: ANOVA test of mean birth weight by HFI status in each season: *, <0.05; **, <0.01

Appendix 6.4: Postpartum weight (A) and MUAC change (B) from 1st to 3rd postpartum month by season and by household food insecurity status

A. Postpartum weight change

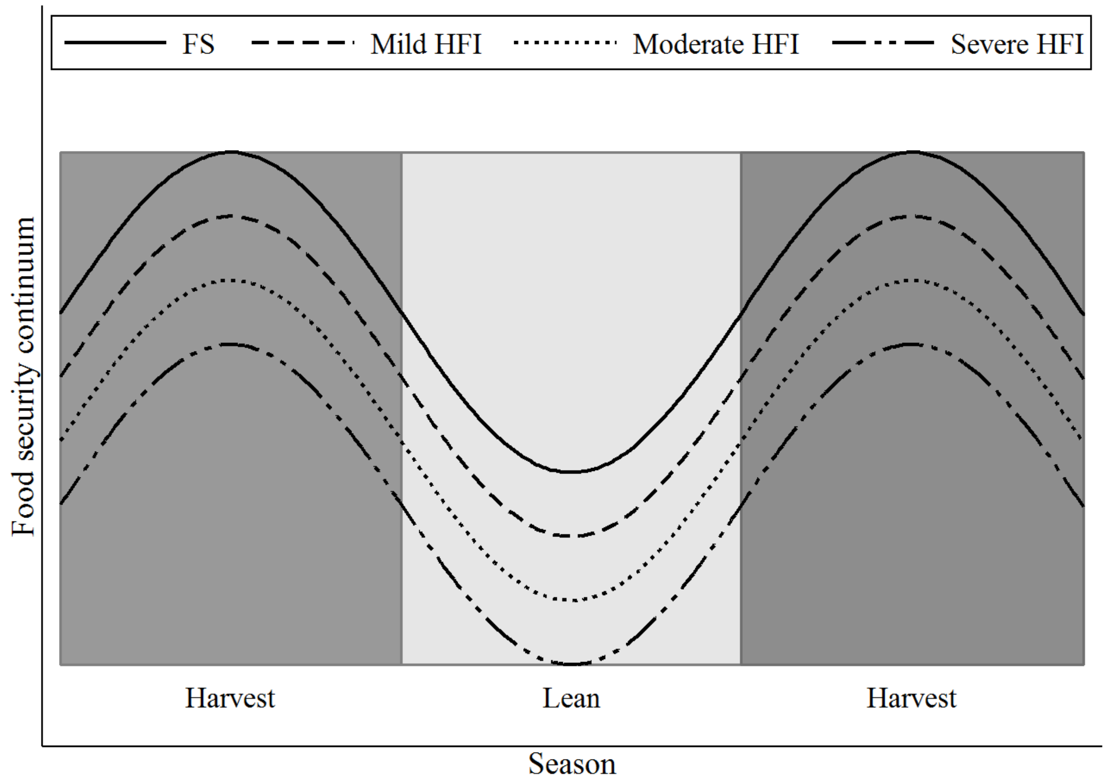


B. Postpartum MUAC change



Note: In each season, the mean weight gain or MUAC change are not significant by HFI status (p>0.11)

Appendix 6.5: Hypothesized static ranking of chronic household food security over the year



Abbreviation: FS, food secure; FI, food insecure

Appendix 6.6: Characteristics of included and excluded households in paper 2

	Included		Excluded		
	n	Mean ± SD or %	n	Mean ± SD or %	p-value[1]
Maternal characteristics					
GA at enrollment	7338	8.8 ± 1.6	11267	13.3 ± 6.6	***
Age, y	7338	23.3 ± 5.3	11357	22.3 ± 5.5	***
Parity	7336		11352		***
0		30.3		45.4	
1		37.3		30.4	
2		20.2		14.5	
≥3		12.2		9.7	
Infant characteristics					
Male	7338	50.7	11526	51.3	0.40
Female		49.3		48.7	
Preterm birth	7338	0.0	10701	28.2	***
Not preterm		100.0		64.6	
Age followed at 6 month					
Socio-economic variables					
HFI score	7338	12.0 ± 4.7	9926	12.0 ± 4.7	0.58
Household size, n	7334	4.1 ± 1.9	11349	4.4 ± 2.1	***
Dependency ratio	7333	0.6 ± 0.4	11349	0.5 ± 0.4	***
Wealth index	7335	0 ± 1	11334	0.1 ± 1.1	***
HFI group	7338		9926		0.23
Food secure		49.6		50.3	
Mild HFI		19.8		20.3	
Moderate HFI		16.0		14.9	
Severe HFI		14.6		14.4	
Religion	7336		11351		0.96
Muslim		91.4		91.3	
Other		8.6		8.7	
Maternal employment	7335		11351		***
Had a paid job		44.8		34.4	
No paid job		55.2		65.6	
Maternal education	7332		11346		***
No education		25.5		22.5	
Primary or higher		74.5		77.5	
Wealth index tertile, %	7335		11334		***
Low		33.5		33.2	
Medium		35.4		32.0	
High		31.1		34.8	

Abbreviations: GA, gestational age; HFI, household food insecurity.

1. P-value is the ANOVA test for continuous variables or Chi-square test for categorical variables.
***, <0.001; **, <0.01; *, <0.5.

Appendix Figures and Tables for Chapter 7

Appendix 7.1: Collinearity of the final model sorted by the value of variance inflation factor (VIF)

Variable	VIF	1/VIF
Parity	2.57	0.39
Maternal age	2.44	0.41
Wealth index	1.73	0.58
Maternal education	1.68	0.60
Severe HFI	1.4	0.71
Birth length	1.29	0.78
Moderate HFI	1.27	0.79
Added suger at 6 mo	1.23	0.81
Mild HFI	1.22	0.82
Had sufficienty BM	1.2	0.83
Added oil at 6 mo	1.17	0.86
Maternal MUAC at 1TM	1.16	0.86
Maternal WDDSs	1.15	0.87
Maternal height at 1TM	1.15	0.87
GA at birth	1.15	0.87
Added formula at 6 mo	1.13	0.88
Fed dairy food at 6 mo	1.13	0.89

Variable	VIF	1/VIF
Fed dal at 6 mo	1.12	0.89
Fed other milk at 6 mo	1.1	0.91
Maternal employment	1.09	0.91
Fed banana at 6 mo	1.07	0.93
Had fever at 6 mo	1.07	0.94
Infant sex	1.06	0.95
Hours interval of measurement since birth	1.06	0.94
Ponderal index	1.06	0.94
Had acute respiratory disease at 6 mo	1.06	0.94
Maternal GA at enrollment	1.05	0.95
BF frequency	1.05	0.96
Fed other food at 6 mo	1.05	0.95
Season at HFI assessment	1.03	0.97
Infant age at 6 mo	1.02	0.98
Blouse wearing at MUAC measurement	1.01	0.99
Had diarrhea at 6 mo	1.01	0.99
Had bloody stools at 6 mo	1.01	0.99

Mean VIF=1.23

Appendix 7.2: Sensitivity analysis: adjusting for maternal BMI at 1st trimester instead of maternal MUAC at 1st trimester in comparing infant weight and length at 6 month of age between mild, moderate and severe HFI group against food secure group[1]

Model index	Variable added	Weight, g			Length, cm		
		Mild	Moderate	Severe	Mild	Moderate	Severe
1	HFI (unadjusted)	**-93 ± 20**	**-130 ± 22**	**-184 ± 22**	**-0.28 ± 0.06**	**-0.40 ± 0.06**	**-0.45 ± 0.07**
2	Infant sex + age	**-86 ± 18**	**-125 ± 20**	**-196 ± 21**	**-0.26 ± 0.05**	**-0.39 ± 0.06**	**-0.48 ± 0.06**
3	Parity+ maternal age +maternal GA	**-79 ± 19**	**-115 ± 20**	**-184 ± 21**	**-0.23 ± 0.05**	**-0.36 ± 0.06**	**-0.48 ± 0.06**
4	Maternal height	**-58 ± 18**	**-78 ± 20**	**-133 ± 20**	**-0.15 ± 0.05**	**-0.21 ± 0.06**	**-0.28 ± 0.06**
5	Maternal BMI	**-45 ± 18**	**-54 ± 20**	**-98 ± 20**	**-0.13 ± 0.05**	**-0.18 ± 0.06**	**-0.23 ± 0.06**
6	WDDS	**-41 ± 18**	**-47 ± 20**	**-87 ± 20**	**-0.12 ± 0.05**	**-0.15 ± 0.06**	**-0.19 ± 0.06**
7	Infant's GA at birth	**-37 ± 18**	**-46 ± 20**	**-82 ± 20**	**-0.1 ± 0.05**	**-0.15 ± 0.06**	**-0.17 ± 0.06**
8	Birth length[2]	-29 ± 16	-32 ± 18	**-64 ± 18**	-0.07 ± 0.04	**-0.10 ± 0.05**	**-0.10 ± 0.05**
9	PI[3]	-22 ± 15	-18 ± 17	**-49 ± 18**	-0.07 ± 0.04	-0.09 ± 0.05	**-0.10 ± 0.05**
10	BF practices[4]	-15 ± 15	-9 ± 17	-27 ± 18	-0.06 ± 0.04	-0.08 ± 0.05	-0.08 ± 0.05
11	CF practices[5]	-17 ± 15	-11 ± 17	-30 ± 18	-0.06 ± 0.04	-0.08 ± 0.05	-0.07 ± 0.05
12	Child morbidity[6]	-17 ± 15	-9 ± 17	-26 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05
13	Maternal employment[7]	-17 ± 15	-9 ± 17	-25 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05
14	Maternal education[8]	-12 ± 15	-2 ± 17	-16 ± 18	-0.05 ± 0.04	-0.06 ± 0.05	-0.05 ± 0.05
15	Wealth index	0 ± 16	15 ± 18	5 ± 19	-0.03 ± 0.04	-0.03 ± 0.05	-0.01 ± 0.05
16	Season	1 ± 16	17 ± 18	4 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05

Abbreviation: GA, gestational age; WDDS, women's dietary diversity score; BF, breastfeeding; CF, complementary feeding;

1. Values are mean ± SE. Bold numbers are significant at 0.05 level.
2. Birth length is adjusted for the hour interval of measurement since delivery.
3. Ponderal index is calculated as birth weight (kg)/length(m)^3
4. Breast feeding practices adjusted include frequency of breastfeeding and whether the baby was reported being fed with enough breast milk from the previous days
5. Complementary feeding practices adjusted are the ones have significant differences across the HFI groups in table 1, including whether or not in the past 7 days infant was fed with formula, milk (powdered or fresh), dairy, dal, banana and other food and whether or not added oil or sugar.
6. Child morbidity adjusted includes whether or not infant had morbidity symptoms of acute respiratory, diarrhea, dysentery and fever in the previous 7 days.
7. Maternal employment is whether or not mother had a paid job at enrollment.
8. Maternal education is the highest women have completed.

Appendix 7.3: Sensitivity analysis: adjusting for birth weight instead of ponderal index in comparing infant weight and length at 6 month of age between mild, moderate and severe HFI group against food secure group[1]

Model index	Variable added	Weight, g			Length, cm		
		Mild	Moderate	Severe	Mild	Moderate	Severe
1	HFI (unadjusted)	**-93 ± 20**	**-130 ± 22**	**-184 ± 22**	**-0.28 ± 0.06**	**-0.40 ± 0.06**	**-0.45 ± 0.07**
2	Infant sex + age	**-86 ± 18**	**-125 ± 20**	**-196 ± 21**	**-0.26 ± 0.05**	**-0.39 ± 0.06**	**-0.48 ± 0.06**
3	Parity+ maternal age +maternal GA	**-79 ± 19**	**-115 ± 20**	**-184 ± 21**	**-0.23 ± 0.05**	**-0.36 ± 0.06**	**-0.48 ± 0.06**
4	Maternal height	**-58 ± 18**	**-78 ± 20**	**-133 ± 20**	**-0.15 ± 0.05**	**-0.21 ± 0.06**	**-0.28 ± 0.06**
5	Maternal MUAC	**-44 ± 18**	**-54 ± 20**	**-94 ± 20**	**-0.13 ± 0.05**	**-0.18 ± 0.06**	**-0.23 ± 0.06**
6	WDDS	**-40 ± 18**	**-46 ± 20**	**-84 ± 20**	**-0.12 ± 0.05**	**-0.15 ± 0.06**	**-0.19 ± 0.06**
7	Infant's GA at birth	**-37 ± 18**	**-47 ± 20**	**-81 ± 20**	**-0.10 ± 0.05**	**-0.15 ± 0.06**	**-0.18 ± 0.06**
8	Birth length[2]	-29 ± 16	-31 ± 18	**-60 ± 18**	-0.07 ± 0.04	**-0.09 ± 0.05**	**-0.10 ± 0.05**
9	Birth weight	-20 ± 15	-15 ± 17	**-43 ± 18**	-0.07 ± 0.04	-0.09 ± 0.05	-0.09 ± 0.05
10	BF practices[3]	-13 ± 15	-6 ± 17	-21 ± 18	-0.06 ± 0.04	-0.08 ± 0.05	-0.07 ± 0.05
11	CF practices[4]	-16 ± 15	-9 ± 17	-24 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05
12	Child morbidity[5]	-16 ± 15	-7 ± 17	-20 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05
13	Maternal employment[6]	-15 ± 15	-6 ± 17	-20 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05
14	Maternal education[7]	-11 ± 15	0 ± 17	-11 ± 18	-0.05 ± 0.04	-0.05 ± 0.05	-0.04 ± 0.05
15	Wealth index	1 ± 16	17 ± 18	9 ± 19	-0.03 ± 0.04	-0.03 ± 0.05	-0.01 ± 0.05
16	Season	2 ± 16	18 ± 18	8 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05

Abbreviation: MUAC, mid-upper arm circumference; HC, head circumference; CC, chest circumference; BMI: body mass index, calculated as weight (kg)/[length(m)2]; GA, gestational age; WDDS, women's dietary diversity score; BF, breastfeeding; CF, complementary feeding;

1. Values are mean ± SE. Bold numbers are significant at 0.05 level.
2. Birth length is adjusted for the hour interval of measurement since delivery.
3. Breast feeding practices adjusted include frequency of breastfeeding and whether the baby was reported being fed with enough breast milk from the previous days
4. Complementary feeding practices adjusted are the ones have significant differences across the HFI groups in table 1, including whether or not in the past 7 days infant was fed with formula, milk (powdered or fresh), dairy, dal, banana and other food and whether or not added oil or sugar.
5. Child morbidity adjusted includes whether or not infant had morbidity symptoms of acute respiratory, diarrhea, dysentery and fever in the previous 7 days.
6. Maternal employment is whether or not mother had a paid job at enrollment.
7. Maternal education is the highest women have completed.

Appendix 7.4: Sensitivity analysis: adjusting factors in a reverse order in comparing infant weight and length at 6 month of age between mild, moderate and severe HFI group against food secure group[1]

Model index	Variable added	Weight, g			Length, cm		
		Mild	Moderate	Severe	Mild	Moderate	Severe
1	HFI (unadjusted)	**-93 ± 20**	**-130 ± 22**	**-184 ± 22**	**-0.28 ± 0.06**	**-0.40 ± 0.06**	**-0.45 ± 0.07**
2	Infant sex + age	**-86 ± 18**	**-125 ± 20**	**-196 ± 21**	**-0.26 ± 0.05**	**-0.39 ± 0.06**	**-0.48 ± 0.06**
3	Parity+ maternal age +maternal GA	**-79 ± 19**	**-115 ± 20**	**-184 ± 21**	**-0.23 ± 0.05**	**-0.36 ± 0.06**	**-0.48 ± 0.06**
4	BF practices[2]	**-67 ± 18**	**-98 ± 20**	**-147 ± 21**	**-0.22 ± 0.05**	**-0.34 ± 0.06**	**-0.43 ± 0.06**
5	CF practices[3]	**-69 ± 18**	**-97 ± 20**	**-143 ± 21**	**-0.21 ± 0.05**	**-0.32 ± 0.06**	**-0.40 ± 0.06**
6	Child morbidity[4]	**-68 ± 18**	**-94 ± 20**	**-138 ± 21**	**-0.21 ± 0.05**	**-0.31 ± 0.06**	**-0.39 ± 0.06**
7	Infant's GA at birth	**-64 ± 18**	**-93 ± 20**	**-133 ± 21**	**-0.19 ± 0.05**	**-0.31 ± 0.06**	**-0.37 ± 0.06**
8	Birth length[5]	**-42 ± 16**	**-56 ± 18**	**-86 ± 18**	**-0.11 ± 0.04**	**-0.16 ± 0.05**	**-0.19 ± 0.05**
9	PI[6]	**-31 ± 15**	**-35 ± 17**	**-62 ± 18**	**-0.11 ± 0.04**	**-0.15 ± 0.05**	**-0.17 ± 0.05**
10	Maternal height	-24 ± 15	-22 ± 17	**-45 ± 18**	-0.07 ± 0.04	**-0.09 ± 0.05**	**-0.10 ± 0.05**
11	Maternal MUAC	-18 ± 15	-11 ± 17	-26 ± 18	-0.07 ± 0.04	-0.09 ± 0.05	-0.08 ± 0.05
12	WDDS	-16 ± 15	-7 ± 17	-21 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.06 ± 0.05
13	Maternal employment[7]	-16 ± 15	-7 ± 17	-21 ± 18	-0.06 ± 0.04	-0.07 ± 0.05	-0.07 ± 0.05
14	Maternal education[8]	-11 ± 15	0 ± 17	-12 ± 18	-0.05 ± 0.04	-0.05 ± 0.05	-0.04 ± 0.05
15	Wealth index	1 ± 16	17 ± 18	8 ± 19	-0.03 ± 0.04	-0.03 ± 0.05	-0.01 ± 0.05
16	Season	2 ± 16	18 ± 18	8 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05

Abbreviation: GA, gestational age; WDDS, women's dietary diversity score; BF, breastfeeding; CF, complementary feeding;

1. Values are mean ± SE. Bold numbers are significant at 0.05 level.
2. Breast feeding practices adjusted include frequency of breastfeeding and whether the baby was reported being fed with enough breast milk from the previous days
3. Complementary feeding practices adjusted are the ones have significant differences across the HFI groups in table 1, including whether or not in the past 7 days infant was fed with formula, milk (powdered or fresh), dairy, dal, banana and other food and whether or not added oil or sugar.
4. Child morbidity adjusted includes whether or not infant had morbidity symptoms of acute respiratory, diarrhea, dysentery and fever in the previous 7 days.
5. Birth length is adjusted for the hour interval of measurement since delivery.
6. Ponderal index is calculated as birth weight (kg)/length(m)^3
7. Maternal employment is whether or not mother had a paid job at enrollment.
8. Maternal education is the highest women have completed.

Appendix 7.5: Sensitivity analysis: adjusting socio-economic factors first in comparing infant weight and length at 6 month of age between mild, moderate and severe HFI group against food secure group[1]

Model index	Variable added	Weight, g			Length, cm		
		Mild	Moderate	Severe	Mild	Moderate	Severe
1	HFI (unadjusted)	**-93 ± 20**	**-130 ± 22**	**-184 ± 22**	**-0.28 ± 0.06**	**-0.40 ± 0.06**	**-0.45 ± 0.07**
2	Season	**-93 ± 20**	**-131 ± 22**	**-191 ± 22**	**-0.27 ± 0.06**	**-0.40 ± 0.06**	**-0.46 ± 0.07**
3	Maternal employment[2]	**-92 ± 20**	**-129 ± 22**	**-191 ± 22**	**-0.27 ± 0.06**	**-0.39 ± 0.06**	**-0.46 ± 0.07**
4	Maternal education[3]	**-59 ± 20**	**-72 ± 22**	**-104 ± 23**	**-0.17 ± 0.06**	**-0.22 ± 0.07**	**-0.20 ± 0.07**
5	Wealth index	-19 ± 20	-18 ± 23	-40 ± 24	-0.06 ± 0.06	-0.07 ± 0.07	-0.01 ± 0.07
6	Infant sex + age	-11 ± 19	-10 ± 22	-47 ± 23	-0.03 ± 0.06	-0.05 ± 0.06	-0.03 ± 0.07
7	Parity+ maternal age +maternal GA	-7 ± 19	-7 ± 22	-51 ± 23	-0.01 ± 0.06	-0.03 ± 0.06	-0.07 ± 0.07
8	Maternal height	-8 ± 18	-4 ± 21	-44 ± 22	-0.02 ± 0.05	-0.02 ± 0.06	-0.04 ± 0.06
9	Maternal MUAC	-10 ± 18	-2 ± 21	-37 ± 22	-0.02 ± 0.05	-0.02 ± 0.06	-0.03 ± 0.06
10	WDDS	-10 ± 18	-1 ± 21	-35 ± 22	-0.02 ± 0.05	-0.01 ± 0.06	-0.03 ± 0.06
11	Infant's GA at birth	-8 ± 18	-3 ± 20	-33 ± 22	-0.01 ± 0.05	-0.02 ± 0.06	-0.02 ± 0.06
12	Birth length[4]	-11 ± 16	-5 ± 19	-33 ± 20	-0.03 ± 0.04	-0.03 ± 0.05	-0.02 ± 0.05
13	PI[5]	-7 ± 16	4 ± 18	-24 ± 19	-0.03 ± 0.04	-0.02 ± 0.05	-0.01 ± 0.05
14	BF practices[6]	3 ± 16	18 ± 18	3 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05
15	CF practices[7]	1 ± 16	16 ± 18	1 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05
16	Child morbidity[8]	1 ± 16	17 ± 18	4 ± 19	-0.02 ± 0.04	-0.01 ± 0.05	0.01 ± 0.05

Abbreviation: GA, gestational age; WDDS, women's dietary diversity score; BF, breastfeeding; CF, complementary feeding;

1. Values are mean ± SE. Bold numbers are significant at 0.05 level.
2. Maternal employment is whether or not mother had a paid job at enrollment.
3. Maternal education is the highest women have completed.
4. Birth length is adjusted for the hour interval of measurement since delivery.
5. Ponderal index is calculated as birth weight (kg)/length(m)^3
6. Breast feeding practices adjusted include frequency of breastfeeding and whether the baby was reported being fed with enough breast milk from the previous days
7. Complementary feeding practices adjusted are the ones have significant differences across the HFI groups in table 1, including whether or not in the past 7 days infant was fed with formula, milk (powdered or fresh), dairy, dal, banana and other food and whether or not added oil or sugar.
8. Child morbidity adjusted includes whether or not infant had morbidity symptoms of acute respiratory, diarrhea, dysentery and fever in the previous 7 days.

Appendix 7.6: Characteristics of included and excluded households in paper 3

	Included		Excluded		
	n	Mean ± SD or %	n	Mean ± SD or %	p-value[1]
Maternal characteristics					
GA at enrollment	12693	10.8 ± 4.5	6057	13 ± 7.2	***
Age, y	12693	23.1 ± 5.5	6147	22 ± 5.3	***
Parity	12693		6140		***
0		34.5		49.6	
1		34.7		30.2	
2		19.0		12.1	
≥3		11.9		8.2	
Infant characteristics					
Male	12693	51.4	6154	50.4	0.20
Female		48.6		49.6	
Preterm birth	12693	18.0	5329	15.6	0.99
Not preterm		82.0		71.0	
Age followed at 6 month					
Socio-economic variables					
HFI score	12693	12.1 ± 4.8	4703	11.7 ± 4.5	***
Wealth index	12693	0 ± 1	6121	0.2 ± 1.1	***
HFI group	12693		4703		***
Food secure		48.6		53.8	
Mild HFI		20.5		18.9	
Moderate HFI		15.6		14.7	
Severe HFI		15.3		12.5	
Maternal employment	12693		6138		***
Had a paid job		41.2		32.9	
No paid job		58.8		67.1	
Maternal education	12693		6130		***
No education		25.2		20.5	
Primary or higher		74.8		79.5	
Wealth index tertile, %	12693		6121		***
Low		34.2		31.6	
Medium		34.9		30.1	
High		31.0		38.2	

Abbreviations: GA, gestational age; HFI, household food insecurity.

1. P-value is the ANOVA test for continuous variables or Chi-square test for categorical variables.
***, <0.001; **, <0.01; *, <0.5.

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Bachelor of Medicine (M.D. equivalent) Jul. 2008
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Graduate Research Assistant Sep. 2010-Mar. 2014
JiVitA Maternal and Child Research Project, Gaibandha, Bangladesh & Baltimore, MD
- Contributed to a grant application to the US Department of Agriculture on literature review
- Designed and implemented multiple surveys, including an innovative local market survey on mobile phones
- Helped co-initiate a randomized controlled trial on complementary feeding and child growth in rural Bangladesh

Data analyst Sep. 2013-Feb. 2014
Dept. of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD
- Analyzed multi-country data from the Demographic and Health Survey (DHS) on women's empowerment
- Assisted results interpretation and wrote sections of the manuscript with the research team

Consultant Sep. 2009-Mar. 2011
HarvestPlus Project, International Food Policy Research Institute, Washington, DC
- Developed baseline crop production and consumption portfolios for six African and South Asian countries
- Evaluated the cost-effectiveness of biofortification projects
- Geo-mapped micronutrient deficiency of vitamin A, iron and zinc for high-risk countries

Research Intern Jun. 2009-Aug. 2009
Sight and Life, Basel, Switzerland

- Reviewed grant proposals related to programs fighting micronutrient deficiencies
- Developed online education program on proposal writing for grant applicants

Research Coordinator Sep. 2008-May 2009
Growing Leaps and Bounds Project, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD

- Developed datasets for study of 240 mother/infant pairs regarding infant feeding practices
- Created a database by using NutriBase 7

Research Intern Jun. 2008-Aug. 2008
National NaFeEDTA Fortified Soy Sauce Program, Chinese CDC, Beijing & Shannxi, China

- Conducted personal questionnaire survey with 200 women in 6 villages in Meixian County, Shannxi Province
- Helped in compiling an infant feeding guiding booklet, Feeding Your Baby: What You Should Know and Q&A

Research Assistant in Health Economics Mar. 2005-Aug. 2007
Beijing Health Service System Research Project, China Center for Economic Research, Beijing, China

- Reviewed literatures, summarized the current status of Beijing community health service

HONORS AND AWARDS

2012-2014	Johns Hopkins Center for Human Nutrition Scholarship
2013	Elsa Orent Keiles Fellowship in International Nutrition
2013, 2014	George G. Graham Research Travel Award
2011	The Harry D. Kruse Fellowship in Nutrition
2010	DSM Micronutrient Research Fellowship
2010	Delta Omega National Honorary Society
2010, 2013	Johns Hopkins Student Conference Fund
2009	Nancy Stephens Student Fund
2004	Peking University Excellence in Community Services and Social Work
2003-2006	Peking University Outstanding Student Scholarship
2003-2006	Peking University Honor of Excellent Student

PUBLICATIONS

Na M, West KP, Shamim AA, Mehra S, Labrique A, Ali H, Wu L, Shaikh S, Klemm R, Christian P. Household Food Insecurity Is Associated with Early Infant Growth But Mediated By Maternal Nutrition During Pregnancy in Rural Bangladesh. Journal of Nutrition. (*Under review*)

Jennings L, **Na M**, Cherewick M, Ahmed S, Hindin M, Mullany B. Women's Empowerment and Male Involvement in Antenatal Care: Analyses of Demographic and Health Surveys (DHS) in Selected African Countries. BMC Pregnancy and Childbirth. (*Under review*)

Zhang FM, **Na MZ**, Zhong XK. The Relationship between Selenium Deficiency and Virus Infection and the Possible Mechanism of Emerging Virus Diseases, a Review from the Aspect of Etiology of Keshan Disease. Chinese Journal of Endemiology, 2008 May 20; 27(3):90-92

PRESENTATIONS

Na M, West KP, Shamim AA, Mehra S, Labrique A, Ali H, Wu L, Shaikh S, Klemm R, Christian P. (2013). Household Food Insecurity and Maternal Dietary Quality during Pregnancy and Early Postpartum Period in Rural Bangladesh. The 7th George G. Gramham Lectureship and Symposium on Micronutrient for life throughout life, Baltimore, MD.

Na M. (2013). Assessing Household Food Insecurity: A balance between internal validity and simplicity. Invited presentation at the Brown bag seminar at the Center for Design and Research in Sustainability (CEDARS), ICF International, Calverton, MD.

Na M, West KP, Shamim AA, Mehra S, Labrique A, Ali H, Wu L, Shaikh S, Klemm R, Christian P. (2013). Development of a Two-item Quick Screen for Household Food Insecurity Assessment. Experimental Biology, Boston, MA. FASEB J April 9, 2013 27:1054.2

Na M, West KP, Shamim AA, Mehra S, Labrique A, Ali H, Wu L, Shaikh S, Klemm R, Christian P. (2012). Difference in Feeding Practice is Associated with Household Food Insecurity in Rural Bangladesh. Oral presentation, South Asian Regional Conference on Breastfeeding and Complementary Feeding, Dhaka, Bangladesh

Na M, West KP, Shamim AA, Mehra S, Labrique A, Ali H, Wu L, Shaikh S, Klemm R, Christian P. (2012). Household food insecurity is directly associated with infant growth but mediated by maternal nutrition during pregnancy in Rural Bangladesh. Oral presentation, International Scientific Symposium on Food and Nutrition Security Information, Food and Agriculture Organization (FAO), Rome, Italy.

Na M, West KP, Shamim AA, Mehra S, Labrique A, Ali H, Wu L, Shaikh S, Klemm R, Christian P. (2011). Association between Household Food Insecurity and Infant Growth in Rural Bangladesh. Experimental Biology, Washington, DC. FASEB J March 17, 2011 25:986.7

TEACHING EXPERIENCES

- Instructor, Introduction of Biostatistics and Epidemiology, JiVitA Project, Gaibandha, Bangladesh (2012-2013)
- Teaching assistant in Food Nutrition Policy (2013), Biostatistical Methods I, II, III (2009-2010), and International Nutrition (2010)

ACTIVITIES & LEADERSHIP

Co-Editor Nov. 2009-Present
China Health Review (ISSN 2325-1557) and CHPAMPS newsletter
China Health Policy and Management Society (CHPAMS), Boston, MA

Journal Reviewer Mar. 2014-Present
Food Security (ISSN 1876-4517)

Co-Founder and President Dec. 2009-May 2013
Chinese Public Health Forum, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD
An organization at Hopkins focusing on academic discussion, career development and social networking among students, scholars and alumni from the Greater China area

Student Representative Mar. 2011, Apr. 2014
Deans' Leadership Workshop in Critical Public Health Challenge, Beijing, China & Baltimore, MD

SKILLS

- Proficient in Microsoft Office and statistics software including STATA, SAS, R, Mplus, and ArcMap
- Native fluency in Mandarin Chinese; Basic proficiency in Bangla and Spanish
- National Computer Rank Examination Certificate Grade 2 (C language programming), National Education Examinations Authority, Ministry of Education of China, 2005

PROFESSIONAL MEMBERSHIPS

2010-Present American Society of Nutrition
2008-Present Global Health Council