THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF NUTRITIONAL SCIENCES

FOOD INSECURITY AND IRON DEFICIENCY IN A COHORT OF NEPALI CHILDREN

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SPRING 2016

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Biobehavioral Health
with honors in Nutritional Sciences

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ABSTRACT

Background: South Asia has the largest food insecure population on the planet, with 3.7 million food insecure living in Nepal alone (2009 est.). Another major public health concern in South Asia is iron deficiency. While we do not have population-level data on the burden of iron deficiency in Nepal, we do know that anemia affects greater than 40% of this population, and that 50% of anemia is typically attributed to iron deficiency.

Objectives: The primary objective of this study was to assess the relationship between food insecurity and iron deficiency in infants living in Bhaktapur, Nepal. We hypothesized that households with greater food insecurity would have children with higher rates of iron deficiency. The secondary objective was to assess the relationship between food insecurity and other relevant indicators of child health including growth, nutrient adequacy, and socioeconomic status.

Design: Infants were followed from birth to 24 months of age (n=236) and household food insecurity was assessed using the Household Food Insecurity Access Scale (HFIAS) every six months. Blood samples were analyzed for ferritin (Ft), transferrin receptor (TfR), and hemoglobin (Hb) at 7, 15, and 24 months. Infant dietary intake was assessed monthly using 24-hour food recalls.

Results: Only 15% of households reported food insecurity, yet iron deficiency was present in 41-49% of infants at 24 months (as assessed by ferritin and transferrin receptor, respectively). No association was found between household food insecurity (HFIAS>1) and iron deficiency (Ft<12ng/mL and/or TfR>8.3mg/L). There was an association between household food insecurity and level of dietary intake of every essential nutrient ($p<0.05$) except protein, carbohydrates, and vitamin B12.

Conclusions: The prevalence of anemia, iron deficiency, and low nutritional adequacy suggest that food insecurity is a concern in this population, and that HFIAS may not be the ideal surrogate marker for detection. Further research should be done to assess the validity of HFIAS in this context.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Laura Murray-Kolb, first and foremost, for taking me and this thesis on one panicked summer day, and for being supportive and encouraging ever since. This process has been challenging but rewarding, and I could not have done it without your guidance.

To my lab team – thank you for assisting me in any way I needed throughout this process. Suzie, thanks for the advice and encouragement (and food), and thanks for chatting with me about Donald Trump and sharing delicious recipes when I just didn't feel like writing anymore. Mihaela, thank you for your guidance and mentorship from start to finish, and thank you for all of the laughs in between! Sam, thank you for your SAS help because… statistics is hard, and thank you so much for letting me crash your trip to Nepal. Ruth, thank you for the SAS help, too, and thank you for sharing your stories of life back in Ghana. I always enjoy talking with you!

To my mom, Becky, thank you for listening to me talk about this thesis constantly and for proofreading when my eyes wouldn't stay open anymore. And to my dad, Carl, your endless encouragement always gives me the strength to keep going, and writing this thesis was no exception.

To my homegirls – Tess, Mary, Menaka, and Jenna – there is no one else I would have rather stayed up on sleepless thesis-writing nights eating Pop Tarts and Kettle Chips with than you crazy kids. You are all endlessly inspiring and I could never have gotten through college, let alone this thesis, without you.

To the MAL-ED Study investigators and the research team in Bhaktapur, this thesis would not be possible without you. Thank you for being so gracious in allowing me to analyze the data that you worked so hard in collecting. Dr. Sanjaya Shrestha and Dr. Laxman Shrestha, thank you both for welcoming me into your country and for allowing me to shadow the data collection. Learning from you and the field team has given me invaluable knowledge in writing this thesis.

To Dr. Crowe and the Erickson Discovery Grant Award Committee, thank you for your financial support of this project and for allowing me to use my leftover funds to travel to Nepal and experience the research happening there firsthand. That experience taught me so much.

Deb Rogers, the free Panera at Schreyer's Thesis Boot Camp provided some serious motivation. Thank you for fueling my thesis writing with sprouted grain bagels and honey cream cheese.

To the Internet, I could never have done this without you. How did people write 90-page research papers before you? By reading books? PubMed and Google Scholar (and CTRL+F), you can stay.

Lastly, I'd like to thank the $20 thesis processing fee for giving me one final thing to complain about with respect to this project. (Your turn to "acknowledge" that this fee exists, Schreyer!)

Chapter 1

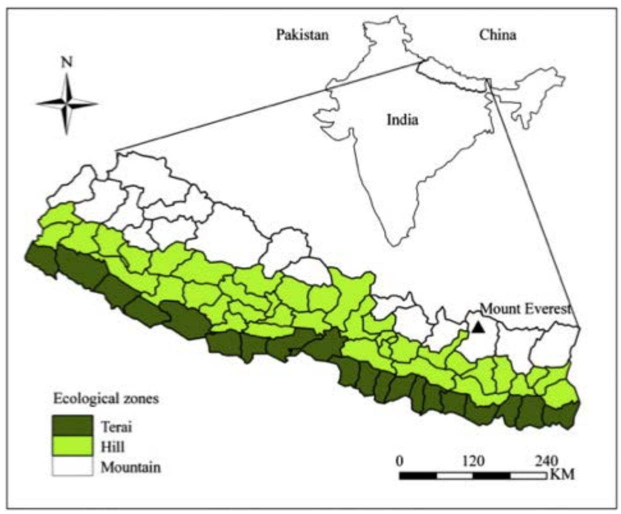
Measuring Food Insecurity: Current Methods and Future Needs

Food security is achieved "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" (FAO, 2002). Food *insecurity*, then, exists when any one of these conditions are not met. A wide range of determinants influence food insecurity, from household income to global food policy, and a number of requirements must be met for a person, household, community, etc. to be labeled "food secure". These nuances make assessment challenging, which is evident in the numerous food security surveys and indicators that exist. Although complex, it is imperative that the international nutrition and public health research communities strive to develop measurements that accurately assess food insecurity for three main reasons: 1) to understand the global burden of food insecurity, 2) to understand the experiences, behaviors, and health consequences of food insecure populations, and 3) to inform the development of appropriate interventions to address food insecurity.

The focus of this first chapter will be the determinants of food insecurity and the tools used to measure household food insecurity. As households do not exist in isolation from larger regional, national, and global contexts, a discussion of broader determinants that cause food insecurity to precipitate at the household level is required. Because this thesis research is based in Nepal, a general geopolitical background of the country will set the stage for discussing food insecurity and its unique determinants there. Ultimately, this chapter will conclude with a discussion on the current methods researchers have used to measure household food insecurity, the efficacy of these measures, and the future directions for improving the methodology. Information on the specific household food insecurity measures that have been used to collect data in Nepal will be included in this section where available and relevant.

Geopolitical Background of Nepal

Nepal is a small country in South Asia located between India and China. The land varies from flat river plains in the south to Himalayan Mountains in the north. Because of these diverse landscapes, Nepal is broken down into three main regions: 1) the Terai, or the tropical low-lying river plains, 2) the temperate central hill region, and 3) the mountain region, in which the Himalayas rise to the subalpine and alpine zones. Kathmandu, Nepal's capital, is located in the Hill region. Temperatures vary from tropical warmth in the Terai to polar cold in the northern regions. Rainfall also varies, with some regions receiving as little as 6.3 inches and others receiving as much as 216.5 inches per year. There are two seasons in Nepal, a wet and a dry season. The wet season lasts from June to September, and the dry from October to May. The months of April and May are particularly vulnerable for many Nepali citizens, as water stress is high due to the long dry season and rising temperatures. Drought is common in these months, but the monsoon season follows from June to August, during which heavy rains restore agriculture production and replenish water sources. Flooding and soil erosion often occur during this time, as well, due to heavy rains on dry land.



Source: Chhetri et al., 2013

Figure 1: Map of Nepal

There are more than 31 million people living in Nepal representing 125 different ethnic groups, and the population is growing quickly, at a rate of 1.79%, compared to India's population growth of 1.22% (CIA World Factbook, 2015). The capital city of Kathmandu is the most densely populated area of Nepal, and 18.6% of the population lives in urban areas. Hinduism is the major religion with 81.3% of Nepali citizens practicing, followed by Buddhism and Islam. The Human Development Index, a composite indicator that evaluates countries based on education, life expectancy, and per capita income, ranks Nepal 145th out of 182 countries assessed (UNDP & Government of Nepal National Planning Commission, 2014). The life expectancy in Nepal is 67 years, ranking the country 166 out of 224 in the world. 63.9% of the population age 15 and over are literate and can read and write. Nepal's Gross Domestic Product is one of the lowest in the world, with 2014 estimates of $2,400 per capita. The risk of infectious disease in Nepal is high, which is compounded by the fact that only 45.8% of the population has improved access to sanitation facilities (CIA World Factbook, 2015). The infant mortality rate is high with 39.14 deaths per 1,000 live births (CIA World Factbook, 2015), and one in five children are born with a low birth weight (The World Bank, 2011). Of children children under the age of 5, 41% were stunted in 2011 (USAID, 2014). To understand these figures, it is helpful to examine Nepal's political history, as government and policy plays a large role in the health and wellbeing of a nation.

Nepal's political history is a tumultuous one. The Shah dynasty ruled Nepal from 1769 to 1850 until the Rana family led a massacre, which established their power and relegated the Shah family to a nominal family with no role in the government. The Ranas led an authoritarian regime, and any opposition or rivals were suppressed. They discouraged education as a form of retaining control over the ignorant masses, and they maintained a close relationship with the British imperial government in India. In 1951, however, anti-Rana rebels overthrew the Ranas. A political turmoil ensued until a constitution was drafted in 1959, leading to government elections. King Mahendra came to power at the time and was opposed to a parliamentary government, so he dismissed the elected officials in 1960 and abolished the constitution in 1962 while establishing a new constitution that gave complete power to the monarch (King Mahendra). His son Birendra succeeded him in 1972, and during his tenure, he agreed to a new constitution and government system – a constitutional monarchy with a multiparty parliamentary system – under which Girija Prasad Koirala became the Prime Minister in 1991. The new government faced a number of economic and ecological problems, which led to more political turmoil. In 1994, Koirala was defeated in a vote of no-confidence, a communist government formed, and then dissolved the next year. A Maoist revolution began with the goal of abolishing the monarchy, and this started Nepal's decade-long civil war. Thousands of civilians were killed in the war. The Maoist rebels stepped up their campaign of violence in 2001 after Prince Dipendra killed the royal family in a drunken shooting spree before committing suicide. Gyanendra was crowned the new king, and he declared a state of emergency in 2001, yet conflict escalated through 2002 until a ceasefire was declared in January 2003. Unfortunately, the ceasefire only lasted until August when fighting broke out again. The war finally ended in 2006 when the parliament voted to curtail the king's political power, and the government and Maoist rebels signed the Comprehensive Peace Agreement. The Maoists joined the government, and in 2008, the monarchy ended when Nepal became a republic with Ram Baran Yadav as first president. Fighting among political parties led the Maoists to leave the government, and the drafting of a new constitution was continually postponed under leadership changes and political gridlock. In September 2015, a new constitution was finally written and adopted. However, minority ethnic groups (primarily Madhesis in the South) seeking more territory and expanded rights felt slighted under the new constitution and deadly protests erupted. India was also displeased with the lack of regard for the Madhesis in the new constitution, as the Madhesis reside close to the Nepal-India border, so India instituted a blockade of that border. Nepal does more than three-quarters of its trade with India (Dixit, 2015), and the blocking of trade has led to a fuel crisis in Nepal. The shortage of fuel as the cooler winter months set in has led to even more protests in the wake of the new constitution.

Amid constant political turmoil and fighting, Nepal has found it challenging to focus on economic and human development. The aforementioned indicators of human health and wellbeing demonstrate Nepal's difficulty in making progress toward improving the quality of life of its citizens. There is hope that, with the passage of the long-awaited constitution, Nepal can focus on strengthening its economy. The conflict with India must end first, which will likely mean amending the constitution to appease some of the Madhesis requests, but changes have already been made and India is beginning to relax their trade restrictions.

Background of Food Security

There are four key pillars on which food security stands – availability, access, utilization, and stability (FAO, 2009). *Availability* refers to the supply of food available, i.e. "Is the supply enough to meet the demand?" *Access* refers to a household's physical, social, and financial access to food. This component addresses questions such as, "Are there roads on which one can travel to get to the nearest food market?" "Is the food culturally suitable?" and "Does one have enough money to purchase food?" *Utilization* refers to how the body processes and retrieves nutrients from food. Questions raised over utilization might include, "Is the diet healthy?" or "Is a person's digestive system healthy and able to absorb nutrients from food?" For example, if a person has chronic diarrhea from drinking contaminated water and is unable to properly digest and absorb nutrients from his or her food, the utilization component of food security is not met. Lastly, the previous three pillars must be present at all times, or *stable*, to achieve food security. Thus, if a community has 1) an adequate food supply, 2) individuals with physical and financial access to that food, 3) diverse foods that foster a well-balanced diet, and 4) individuals are free of disease, but the community experiences seasonal droughts that compromise their food supply two months out of the year, then that community would **not** be considered food secure.

Article 25 of the United Nations Declaration of Human Rights reads "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control" (United Nations [UN], 1948). Although the UN recognizes food as one of our most basic and inalienable human rights, the Food and Agriculture Organization (FAO) of the UN reported that in 2015, 795 million people in the world were undernourished (FAO, IFAD, & WFP, 2015). While Sub-Saharan Africa has the largest *proportion* of hungry people, with 23.2% of the population food insecure, South Asia has the highest *number* of food insecure people in the world with an estimated 281 million people (FAO, IFAD, and WFP, 2015).

Determinants of Food Insecurity

As our world continues to become more interconnected through globalized economies, communications, and international trade, the determinants, or causes, of food insecurity continue to grow. Not only do local influences such as regional food production and access to local markets affect household food security, but global geopolitical forces now play an ever-increasing role, as well. For example, trade liberalization in developing countries (mandated by global development banks) has had an enormous impact on national and local food security all over the world. This section explores determinants of food insecurity at global, national, and local levels and how they converge to predict food security status at the household level. These include poverty, international policies, political instability, price shocks, and food aid and food assistance.

Poverty

The World Bank (2015) estimated that in 2012, 896 million people were living in extreme poverty, measured by those living on less than $1.90 per day. Eighty percent of these people were living in South Asia and Sub-Saharan Africa (World Bank, 2015a). In Nepal specifically, one in four people were living in extreme poverty in 2011 (World Bank, 2015b). Fortunately, this number fell dramatically in just seven years, as more than half of Nepal's population was living in extreme poverty in 2004 (World Bank, 2015b).

Poverty precipitates food insecurity in a number of ways. The most obvious is a lack of financial capital with which one can purchase food. This is consistent with data that the world's poorest spend a larger share of their income on food than the rest of the population (USDA Economic Research Service, 2015). Poverty also contributes to food insecurity when considering the type of diet that one can purchase with limited funds. The world's poor have limited financial access to a variety of foods, especially to energy- and nutrient-dense meats and animal products. Pregnant women in poverty are less likely to receive adequate nutrition for the aforementioned reasons and more likely to give birth to malnourished children (Larson, 2007), contributing to a generational cycle of food insecurity. Access to clean water, quality housing, and health services is also limited when living in poverty, and this can contribute to poor health status. Children in poverty are less likely to receive a quality education, and thus more likely to stay in poverty as adults (van der Berg, 2008). There are many ways in which poor health contributes to food insecurity, especially in the developing world. For example, if a household cannot reliably retrieve clean water, it is likely that water-borne illnesses, such as intestinal parasites or chronic diarrhea, will contribute to the malabsorption of food. Not receiving adequate nutrients from consumed food is an indicator of food insecurity, as it fails to fulfill the "utilization" requirement of food security. Oftentimes, these effects of poverty conspire to create a vicious cycle of poverty/food insecurity. If you are born into poverty, there is a much greater likelihood that you will have stunted growth and cognitive development, poorer health, lesser education, and poorer job prospects (van der Berg, 2008), making it increasingly difficult to break the cycle of poverty and achieve food security.

It is evident that poverty contributes to food insecurity in a number of ways and that these relationships are also oftentimes bidirectional – food insecurity can feed back on and contribute to poverty, as well, through mechanisms like having ill health or selling household assets to increase food supplies. But if poverty remains the largest predictor of food insecurity, then what causes poverty?

International Policies

In the 1940s, the World Bank (then the International Bank for Reconstruction and Development) and the International Monetary Fund (IMF) were created to provide loans to "third world" countries to promote international development. While theorists differ on what constitutes "development," it is most commonly conflated with "economic development"; global development banks often use this definition. In the early years of the World Bank and the IMF, loans were provided to individual countries for bolstering public sector activities, such as investments in education and infrastructure, under prevailing

Keynesian economic theory. In the 1970s, however, economic downturn left recipient countries in poor condition to pay back their loans, and the accumulation of interest on those loans made repayment even more difficult. The emerging (and currently prevailing) economic development theory soon became *neoliberalism,* which favored private sector growth and limited government. Countries indebted to global development banks were then forced to remove many of their investments from the public sector to invest in the development of the private sector. This undertaking is referred to as *structural adjustment*.

Nepal embraced the neoliberal economic policies that the IMF and World Bank implemented in the country in the 1980s. A series of programs including privatization of public operations, market-centered economic development, and trade liberalization promised economic growth and prosperity in one of the poorest countries in South Asia. However, a wealth of development indicators show that after structural adjustment, the country did not make improvements as promised, facing stagnant growth, widening inequality, increased poverty, and rising social tension (Khatiwada & Sharma, 2002). These neoliberal policies had huge implications for agriculture and food security in Nepal, as well. There was pressure from international development banks in the 1980s for Nepal to open its borders and embrace free trade through the removal of tariffs and encouragement of exports. This also meant removing agriculture subsidies and other government protections that historically supported Nepali farmers. A country whose economy once depended heavily on its agriculture sector shifted to rely on service and industry. In 1975, agriculture made up nearly 72% of Nepal's economy, and post-structural adjustment, agriculture's percentage share fell to less than 40% of the economy (Khatiwada & Sharma, 2002). This decline in agriculture meant a decrease in Nepal's self-sufficiency for providing food for its citizens and an increased reliance on foreign imports to feed its people. After structural adjustment, Nepal went from a net exporter of agricultural goods to a net importer, and Nepal has suffered a food deficit ever since. Table 1 below shows how agriculture as a percentage of GDP has declined since 1985.

Table 1: Agriculture as a Share of GDP Nepal

Sectors	1975	1980	1990	2000	2004
Agriculture	**71.6**	**61.8**	**50.6**	**39.5**	**38.7**
Non Agriculture	**28.4**	**38.2**	**49.4**	**60.5**	**61.3**
Mining and Quarrying	0.1	0.2	0.5	0.5	0.5
Manufacturing	4.2	4.3	6.0	9.2	7.7
Electricity, Gas, and Water	0.2	0.3	0.5	1.6	2.3
Construction	3.7	7.2	9.0	10.2	10.3
Trade, Restaurant, & Hotel	3.4	4.1	10.5	11.7	10.4
Transport & Communication	4.3	7.0	5.7	8.0	9.2
Finance and Real Estate	6.9	8.4	9.3	10.1	10.9
All others	5.7	6.8	7.9	9.2	9.8
Total GDP	**100**	**100**	**100**	**100**	**100**

Sources: Khatiwada and Sharma *(2002)*, Table 2.1; Asian Development Bank, *Key Indicators 2005*.

Since 1990, total food production has been deficient, meaning there is not enough food produced to feed Nepal (FAO, 2010). In 2013, Nepal imported one-fifth of its food (World Bank, 2015b). This can be attributed to decreased investment in Nepali agriculture, especially in places where production is vulnerable to begin with. For example, the poorer hill and mountain regions are particularly susceptible to low production and thus high food insecurity due to the reliance on traditional farming methods with limited access to agriculture extension services, technology, and credit. Drastic weather events such as flood and drought make production all the more vulnerable. When governments are not investing in protecting farmers from these risks and providing them access to essential technologies that can buffer against risk, production and food security faces greater instability. To serve as comparison, the United States government and many European governments retain heavy involvement in their agricultural sectors through the provision of direct payments, subsidies, agriculture extension services, etc., and these investments have made American and European farmers the world's top food producers (although these investments have also significantly contributed to other agriculture and health-related issues such as the obesity epidemic, loss of agrobiodiversity, etc.). This has been one of the predominant criticisms of neoliberalism – global development banks (staffed by Americans and Europeans, primarily) prohibit developing countries from investing in agriculture while developed countries provide huge supports to their farmers domestically.

Political Instability

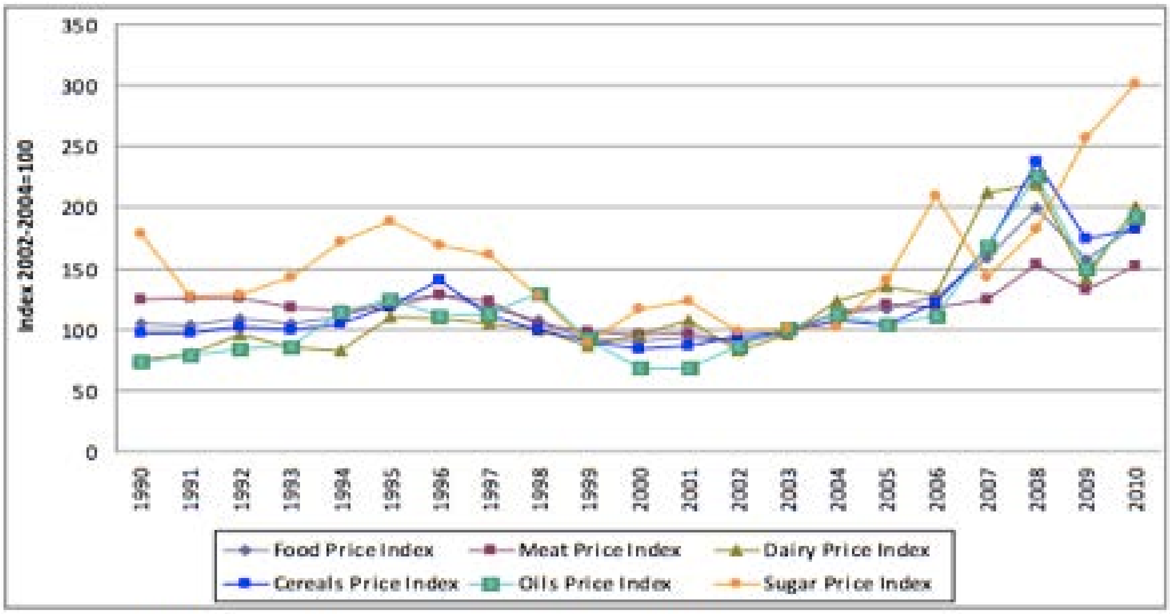
Political instability and/or conflict can contribute to food insecurity at every level of the food system. It can disrupt production through conflict over land, reduced access to resources by farmers, or destruction of farmland (Deaton & Lipka, 2015). Land disputes, for example, can disrupt the ability of farmers to sell their products in markets through conflict over control of roads on which farmers travel to sell their goods. On the consumer side, political instability usually relates to income insecurity, as job markets are not typically secure during times of conflict. Oftentimes, consumers have diminished capacity to financially access food. Additionally, they may have the same troubles in physically accessing markets as farmers do. At the government level, in times of political instability, investments are often removed from social programs that may promote food security to fund security efforts. Moreover, as with poverty, a bidirectional relationship exists here – political instability can cause food insecurity and food insecurity can cause political instability (Maxwell, 2012). This is evident in the 2008 food riots that occurred all over the world in response to global price shocks that made basic commodities unaffordable in many parts of the world. These price shocks will be discussed in the next section of this literature review.

Nepal has a strong history of political conflict, and its relationship to food security has been well researched. In 1996, the decade-long civil war, when the Communist Party Nepal-Maoist (CPN-M) sought to overthrow the monarchy, is believed to have made a large impact on Nepal’s food security (Do & Iyer, 2010). Federal funds shifted towards military spending and away from social programs, land and infrastructure was seized and destroyed, and people’s livelihoods were disrupted in areas of conflict contributing to losses of business and income. Non-governmental Organizations (NGOs) halted food shipments in some areas, as they were not reaching the intended populations and instead fueling armies. In one region of Maoist occupation, there were reports that Nepali soldiers forbade people from carrying more than one day’s worth of food at a time, despite the nearest market being a three or four days walk away, as a tactic for depriving Maoist rebels of food (Upreti, Sharma, & Paudel, 2014). Many attribute the improved food security and decrease in negative child health outcomes associated with food insecurity (stunting, in particular) in the past decade in part to the end of Nepal’s civil war.

Price Shocks

Beginning in 2006, the price of global commodities soared, eventually peaking in 2008. There are a number of reported causes for these price spikes. Most often, they are attributed to increased speculation in commodity food markets (especially grain) by investment banks (Tadesse, Algieri, Kalkuhl, & von Braun, 2013). This increased investment led to demand shocks that disrupted the laws of supply and demand, especially when coupled with rising population, fertilizer price spikes, and increased demand for more resource intensive food from China, Brazil, India and other developing countries (Trostle & Seeley, 2013). (“Resource intensive food” usually refers to the increased production and consumption of meat and animal products and processed foods.) Moreover, the conversion of commodity crops/agricultural land to biofuel production is considered to have decreased global food supply during this time contributing to price increases. For these reasons, global food supply decreased, demand increased, and prices rose dramatically (Tadesse, Algieri, Kalkuhl, von Braun, 2013). For poor developing countries that, after structural adjustment, had decreased self-sufficiency and became net importers of food, these price spikes had crippling effects (IFAD, 2011).

As Figure 2 illustrates, cereal prices during this time rose dramatically, more than doubling from 2006 to 2008 (FAO, 2011). Cereals include wheat, rice, and corn, among other grains – staple foods in the majority of the world’s diets. Those living in poverty rely especially on these cheaper commodities to form the basis of their diets, but the price shocks in 2008 made it very difficult to afford even these basic staple foods.



Source: Food and Agriculture Organization of the United Nations, 2011.

Figure 2: Global Commodity Price Shocks, 1990-2010

While higher-income countries felt the impacts of increased food prices marginally, the impacts on lower-income countries, like Nepal, were vast. For example, a 10 cent increase in the price of a bag of rice might not have made a big impact on American citizens, where the GDP per capita was $48,970 in 2008 (World Bank, 2015a). In Nepal, however, the same increase would have meant much more, as GDP in 2008 was equivalent to 1,810 US dollars (World Bank, 2015b). FAO (2008) estimated that high food prices drove an additional 75 million people globally, including 41 million people in the Asia and Pacific region, into hunger following the crisis.

In Nepal, these global price shocks caused 3.7 million additional people to fall into food insecurity (MoAC, WFP, & FAO, 2009). The price shocks came right after the end of the civil war, when land disputes caused many to rely on purchasing rather than producing their food (Upreti, Sharma, & Paudel, 2014), and right before a winter drought that left wheat and barley yields down 14.5% and 17.3%, respectively (MoAC, WFP, & FAO, 2009). These shortages plummeted another estimated 707,000 Nepali citizens into food insecurity (MoAC, WFP, & FAO, 2009).

As more and more people fell into food insecurity in Asia and Africa during the 2008 price spikes, civil unrest erupted in the form of “food riots.” Ten thousand workers rioted in Bangladesh

(Ramesh, 2008), 400,000 workers rioted in Egypt (Bush, 2010), soldiers were mobilized in Burkina Faso to quell the uprisings occurring throughout the country and approaching the capital (IRIN, 2008), 24 people died in riots in Cameroon (Bureau of Democracy, Human Rights, and Labor, 2009), and deadly riots in Haiti led to government collapse (Guyler Delva & Loney, 2008). Luckily, the food riots in Nepal were not as deadly as some of the aforementioned. In Nepal, riots were reported in the most food insecure mountain and hill regions of the west, primarily in response to the poor quality food that communities were given as food assistance during this time (Gurubacharya, 2008; FAO, 2010).

Food Aid & Food Assistance

The history of food aid and food assistance is a complicated one. While the differences are nuanced, food aid refers to international funding of commodity donations to low-income countries, whereas food assistance is more comprehensive by including vouchers and cash transfers with special focus on nutrition (Harvey, Proudlock, Clay, Riley, & Jaspars, 2010). Food aid, developed first, was created so that wealthy countries with surplus commodities could donate some of their surpluses to countries in need. The United States developed their own food assistance program in the 1950s – Public Law 480 (P.L. 480), also known as “Food for Peace,” and the World Food Programme (WFP) became the United Nation’s food assistance program in the 1960s (Clay, 2003). The motivations behind donating food are unclear – original proponents of American food assistance programs cited a moral obligation for feeding the world’s hungry while preventing the spread of communism by promoting friendly relations between “third-world” nations and capitalist nations (Ball & Johnson, 1996). The WFP began in the 1960s after George McGovern (then Director of Food For Peace) suggested its formation to the UN. The World Food Program started as a small branch of the UN focused on development through food aid but grew to a large multilateral organization focused on food assistance especially in times of disaster.

Globally, food aid as a means of international development has decreased since the 1970s, and is reserved primarily for immediate relief in the face of acute disaster. There are many reasons for this. One notable cause is that grain price spikes in 1995-1996 led the US and EU to dramatically reduce their food aid due to cost (Murphy & McAfee, 2005). During that time, structural adjustment was also occurring, and dominant economic theory led the US and WFP to reduce their foreign aid in favor of a free market economy (Clay, 2003). There were also many criticisms regarding the effectiveness of foreign food aid as a mechanism for development. There was little proof that dumping surplus commodities in developing countries was doing anything to promote growth and development within the recipient nations. In fact, in many ways, the donation of these commodities served to undermine the recipients' capacities for strengthening their own economies, especially their agriculture sectors. This is primarily a function of increased dependence on outside resources and an inability for farmers to make adequate income due to the widespread market availability of cheaper commodities grown in the United States but sold locally.

Many argue that this "disincentive" effect of food aid for domestic agriculture production has occurred in Nepal. Nepal was one of the first countries to receive food aid from the US government in the cold war period for diplomatic purposes due to its strategic location, given its proximity to China (Khadka, 2000). One of the primary goals was economic development through investment in Nepal's agriculture sector. Because US foreign aid occurred at a time when Nepal was going through a number of other changes (namely, political conflict) it is difficult to understand what impacts food assistance had on Nepal as a whole. However, there is no evidence of any economic prosperity through agriculture development during the Cold War period of heightened US food aid (Khadka, 2000).

Another challenge associated with the food aid in Nepal is the acceptability of the donated food. If the supply of donated food is mostly cereal grains, recipients get little nutritional value from grains such as maize and rice, as these foods are primarily starch with few micronutrients. Moreover, problems with the standards of donated food is of concern. For example, following the 2015 earthquake in Nepal, the WFP was accused of delivering poor quality food to communities in need. Two districts accused the WFP of providing inedible, black, rotten rice (Adhikari, 2015). The WFP investigated and denied the claims. They reported finding no evidence of rotten rice – only rice stores with broken rice grains at a higher level than preferred (World Food Programme, 2015). Pulses of substandard quality were also delivered after the earthquake to communities in need. The WFP admitted that these pulses were inedible, but they said they were not authorized for distribution within the country, and were separate so that they could be disposed of (Ekantipur Report, 2015). The storage and delivery of donated food is a contested issue and deeply connected to cultural and regional acceptability. Unfortunately, the WFP themselves performed the only investigations into the rice and pulses disputes, so it is unclear whether or not the allegations had any truth to them given the clear conflict of interest.

These broad determinants of food insecurity converge at national, community, and household levels to produce food insecure populations. One challenge of the international public health and health policy communities has been to develop a measurement tool that accurately assesses food insecurity. Having accurate measurements is integral in identifying food insecure households, developing population-level estimates of food insecurity, and developing targeted interventions to fight food insecurity. This next section will discuss the benefits and drawbacks of seven measures that the international research community has developed to assess food insecurity at the household level.

Measuring Household Food Insecurity

Given the multidimensional nature of food insecurity, it can be difficult to accurately measure. There have been multiple methodologies developed for assessing food security, but these methods can be inconsistent when compared to one another; one measurement can yield vastly different results from another measurement when used in the same context (Webb et al., 2006). These measurements also tend to vary when used in different world regions, as some measurements developed in one location are not valid across contexts. Refining the way we assess food insecurity and understanding the strengths and limitations of the current methods are important in furthering the efforts to tackle global hunger.

There are seven main methods for assessing household food insecurity as used by leading global institutions such as the Food and Agriculture Organization (FAO), the World Food Programme, and US Agency for International Development (USAID). All are household surveys in some capacity, but each method asks different questions to target different aspects of food security. These methods include:

1. Coping Strategies Index (CSI)
2. Reduced Coping Strategies Index (rCSI)
3. Food Consumption Score (FCS)
4. Household Dietary Diversity Score (HDDS)
5. Household Food Insecurity Access Scale (HFIAS)
6. Household Hunger Scale (HHS)
7. Household Consumption and Expenditure Surveys (HCES)

Coping Strategies Index

The first method, the Coping Strategies Index (CSI), measures culturally relevant coping strategies associated with food insecurity. Used by FAO and the WFP, the general question that the CSI seeks to answer is “What do you do when you don’t have enough food and don’t have enough money to buy food?” (Maxwell & Caldwell, 2008). Prior to using the Coping Strategies Index in the field, local assessments must be made to determine context-specific coping behaviors that are practiced in response to food shortages, as well as how often those coping behaviors are used as well as their relative severity. This information is used to develop the Coping Strategies Index and guide how it is scored (for example, a household that answers yes to a coping behavior that has been identified as severe might receive a higher score than other households that report less severe coping behaviors). There are four main types of coping strategies that each CSI should address when developing the questionnaire: 1) changing diets, 2) household attempts to increase food supply using unsustainable short-term strategies, 3) reducing the number of people in the household by sending them elsewhere, and 4) rationing food within the household (Maxwell & Caldwell, 2008). Once a set of coping strategies are identified and weighted by severity, the survey can be administered within households. An example of a Coping Strategies Index survey is shown in Table 2 below.

Table 2: Coping Strategies Index Survey Questions

Behaviors	**Frequency**
In the past 7 days, if there have been times when you did not have enough food or money to buy food, how many days has your household had to:	Number of days out of the past seven:
a. Rely on less preferred and expensive foods?	
b. Borrow food, or rely on help from a friend or relative?	
c. Purchase food on credit?	
d. Gather wild food, hunt, or harvest immature crops?	
e. Consume seed stock held for next season?	
f. Send household members to eat elsewhere?	
g. Send household members to beg?	
h. Limit portion size at mealtimes?	
i. Restrict consumption by adults in order for small children to eat?	
j. Feed working members of HH at the expense of non-working members?	
k. Reduce number of meals eaten in a day?	
l. Skip entire days without eating?	

Source: Maxwell & Caldwell, 2008

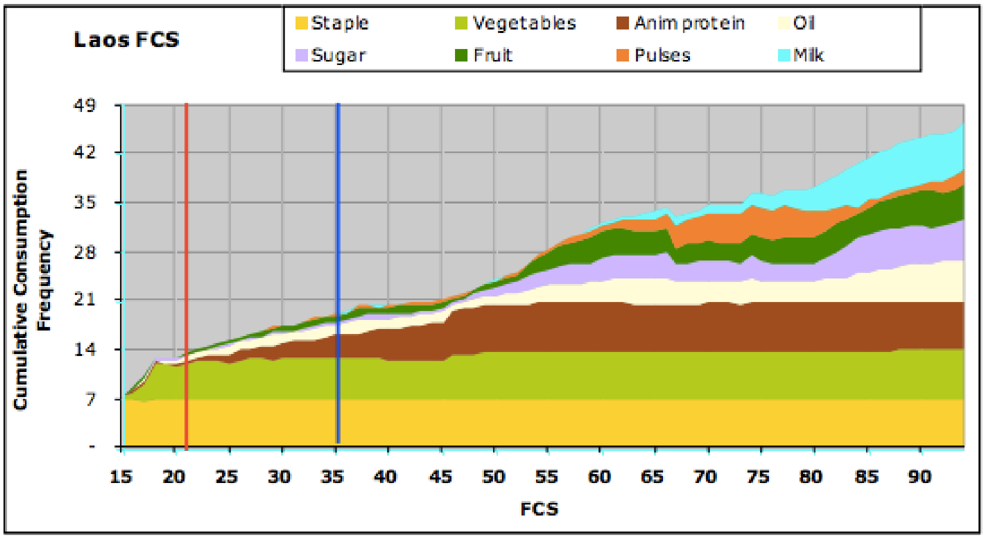
The benefits of the Coping Strategies Index are that it is a quick, simple, and cheap tool that can be used to measure impact of interventions and food aid programs and can provide early warning of impending food crises. Some drawbacks are that the CSI provides little information about causal factors and that it must be adapted locally before being applied.

Reduced Coping Strategies Index

The Reduced Coping Strategies Index (rCSI) is a condensed version of the Coping Strategies Index. The rCSI is a universal subset of coping behaviors rather than a culturally relevant set of coping behaviors. Thus, the survey does not need prior community assessment to gather local coping strategies. The rCSI has been found to be relevant in 14 contexts (Maxwell & Caldwell, 2008), and it is primarily promoted by the WFP. The major benefit of the reduced Coping Strategies Index in comparison to the Coping Strategies Index is that scores can be compared across context, as the measurement is universal. It is also quicker and easier than the CSI. A drawback is that the rCSI tends to only measure less-severe coping behaviors and therefore it cannot accurately identify the most severely food insecure households in a given context due to its limited scope. Neither the Coping Strategies Index nor the reduced Coping Strategies Index has been used as a method for measuring food insecurity in Nepal.

Food Consumption Score

The Food Consumption Score (FCS), also promoted by the WFP, measures dietary diversity and food frequency with special attention to nutrition. Under this tool, a 7-day recall of household food consumption is used to identify how much of each food group is consumed within that household. The frequency of consumption for each food group is compared to established thresholds to create a household food consumption score. An example of the Food Consumption Score's thresholds is shown in Figure 3. A score above 35 is food secure, while a score between 21.5 and 35 is moderately food insecure and a score below 21 is severely food insecure. Recent research has demonstrated a correlation between FCS and caloric adequacy measures (Coates et al., 2007). A benefit to this method is that it provides a more comprehensive analysis of overall household diet with respect to nutrition rather than total food consumption. Researchers examining the validity of the FCS in varying contexts, however, have identified multiple drawbacks. One study found the FCS established thresholds not to be universal, and that adapting the methodology to each context would be too expensive (WFP, 2010). Another study's results supported this claim by finding that in Uganda, Laos, and Burkina Faso, thresholds must be amended for localities to correlate (Kennedy et al., 2010). The FCS has also been criticized for underestimating the prevalence of food insecurity (Coates et al., 2007).



Below the red line is "poor" food consumption, between the red and blue is "borderline" food consumption, and above the blue line is adequate food consumption
Source: WFP 2008

Figure 3: Food Consumption Score Example, Laos

The Food Consumption Score has been used in Nepal in 2010/2011 as part of a Nepal study on food insecurity. Nepal's National Planning Commission Central Bureau of Statistics reported that 20% of households had an inadequate food consumption (score of less than 42) and 10% had a poor food consumption (score of less than 28) (Nepal National Planning Commission, 2013). These figures were worse in the rural areas than in urban areas.

Household Dietary Diversity Score

The Household Dietary Diversity Score (HDDS) is similar to FCS but with a 24-hour recall period rather than a 7-day recall period. This method for measuring household food insecurity is also promoted by FAO and USAID. The benefits are that it is simpler than the FCS because of the time frame, and there is less recall bias given that participating households do not have to remember everything that they ate in the previous week – data on the previous day's diet is much more likely to be accurate. The major drawback to the HDDS, however, is that there is no food frequency information, which is also a function of the reduced time frame. Thus, it is a less comprehensive measure of dietary diversity and consumption patterns than the FCS. The Household Dietary Diversity Score is a simpler tool, but because of its simplicity, it provides less information about household diet and food insecurity.

In the same 2010/2011 Nepal Living Standards Survey that used FCS as an indicator for food insecurity, surveyors used the same data to calculate dietary diversity in a method similar to the Household Dietary Diversity Score. The recall period was still seven days however, unlike the 24-hour recall period in the standard HDDS promoted by FAO and USAID. A Dietary Diversity Score (DDS) was calculated based on how many of eight selected food groups participants reported consuming in the past week. The average Dietary Diversity Score for Nepal was 6.5, however, there were regional differences ranging from scores of 6.07 in the western rural hills to 7.24 in urban Kathmandu (Nepal National Planning Commission, 2013). Additionally, a large proportion of households reported consuming many of their calories from staple foods, which indicates poor overall diet. For example, even if a household is regularly consuming 6-7 out of 8 food groups but the majority of their energy is coming from rice, maize, or wheat, they are likely food insecure due to inadequate nutrient intake present from fruits and vegetables. Figure 4 illustrates the findings from the HHDS data in Nepal, showing a higher proportion of households in the rural areas reporting low dietary diversity with a high/very high share of energy from staple foods than households in the urban regions. (High staple diets were defined as consuming more than 60% of calories from staple foods while very high staple diets were defined as more than 75% of calories from staple foods).

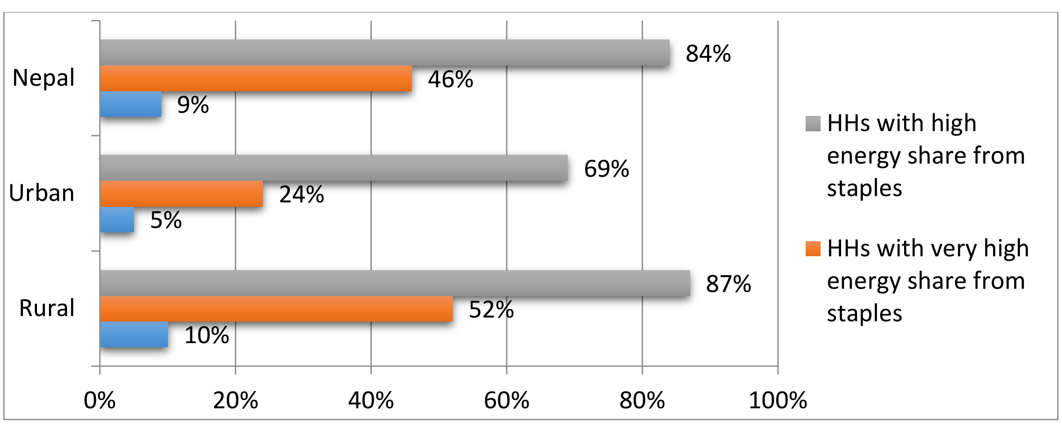


Figure 4: Dietary Diversity in Urban vs. Rural Nepal, 2010/11

Household Food Insecurity Access Scale

The Household Food Insecurity Access Scale (HFIAS) is promoted by both FAO and USAID. This method is similar to the CSI and rCSI in that it also measures behaviors associated with food insecurity. What sets this measurement apart, however, is that its questions address not only the strategies used to cope with food shortages, but also household anxiety over inadequate food access (Maxwell, Coates, & Vaitla, 2013). This survey has nine questions and is scored based on severity of each respective question that was answered affirmatively (shown in Table 3 below). Some benefits are that it is very easy to administer given its length and that it is also standardized to allow for better comparison. However, as mentioned for some of the aforementioned indicators, as more research is done to examine the validity of these measures, we are finding that there are contextual differences in these nine questions and the way they are answered. A 2009 study examined the validity of the Household Food Insecurity and Access Scale in rural Tanzania (Knueppel, Demment, & Kaiser, 2009). Interviews with key informants were conducted to identify households to participate in the study, and then surveys were administered to mothers of the 237 chosen households. While the results showed that the HFIAS successfully identified components of insufficient food quality and insufficient food intake, the researchers found the HFIAS to be lacking in identification of anxiety/worry over food (Knueppel, Demment, & Kaiser, 2009). For example, the least severe question for determining food insecurity was not the question that was answered most affirmatively (Knueppel, Demment, & Kaiser, 2009). This may suggest that the developers of HFIAS incorrectly predicted which questions were least and most severely experienced in food insecure households. More research must be done to address these limitations, and perhaps a restructuring needs to occur to allow cross-context comparison.

Table 3: HFIAS Survey Questions

No.	Occurrence Questions
1.	In the past four weeks, did you worry that your household would not have enough food?
2.	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?
3.	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?
4.	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?
5.	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?
6.	In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?
7.	In the past four weeks, was there ever no food of any kind in your household because of lack of resources to get food?
8.	In the past four weeks, did you or any household member go ot sleep at night hungry because there was not enough food?
9.	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?

Source: Coates, Swindale, & Bilinsky, 2007

Household Hunger Scale

The Household Hunger Scale (HHS), derived from the Household Food Insecurity Access Scale, measures behaviors associated with household food insecurity. The Household Hunger Scale, however, asks only three specific questions in its survey, none of which are psychological. Thus, it is quicker than the nine-question HFIAS and it is also reported to be culturally invariant. Again, drawbacks to the HHS are that it provides a less complete picture of household food insecurity, including its severity. The HHS does not account for perceptions, which could be beneficial as sometimes communities that have chronically faced food insecurity do not properly appraise it as such, given that food insecurity is commonplace.

Both the Household Food Insecurity and Access Scale and the Household Hunger Scale have been administered as part of the Malnutrition and Enteric Infections: Consequences for Child Health and Development (MAL-ED) study in Nepal, and data from the HFIAS will be used in this study. In a preliminary analyses of MAL-ED data testing the validity of these two food insecurity indicators against anthrompometric measures of food insecurity (stunting and wasting), researchers found a stastically significant positive correlation between HFIAS and stunting, but not wasting. Furthermore, they found no statistically significant relationship between HHS and stunting or HHS and wasting (Psaki et al., 2012). Thus, the HFIAS was chosen for future data collection among Nepali households in MAL-ED, given that it provides greater information and more reliable data than the HHS.

Table 4: HHS Survey Questions

No.	Question	Response Option
Q1	In the past [4 weeks/30 days], was there ever no food of any kind in your house because of lack of resources to get food?	0 = No (Skip to Q2) 1 = Yes
Q1a	How often did this happen in the past [4 weeks/30days]?	1 = Rarely (1-2 times) 2 = Sometimes (3-10 times) 3 = Often (more than 10 times)
Q2	In the past [4 weeks/30days], did you or any household member go to sleep at night hungry because there was not enough food?	0 = No (Skip to Q3) 1 = Yes
Q2a	How often did this happen in the past [4 weeks/30days]?	1 = Rarely (1-2 times) 2 = Sometimes (3-10 times) 3 = Often (more than 10 times)
Q3	In the past [4 weeks/30days], did you or any household member go a whole day and night without eating anything at all because there was not enough food?	0 = No (Skip to next section) 1 = Yes
Q3a	How often did this happen in the past [4 weeks/30days]?	1 = Rarely (1-2 times) 2 = Sometimes (3-10 times) 3 = Often (more than 10 times)

Source: Ballard, Coates, Swindale, & Deitchler, 2011

Household Consumption and Expenditure Surveys

The seventh method, Household Consumption and Expenditure Surveys (HCES), is a blanket term for hundreds of different surveys that target both food consumption and food acquisition using Household Income and Expenditure Surveys (HIES), Living Standards Monitoring Surveys (LSMS), and National Household Budget Surveys (NHBS) (Fiedler, Lividini, Bermudez, & Smitz, 2012). The frequency with which HCES's are being used is increasing – in 1990, the World Bank reported 22 low- and middle-income countries using household consumption and expenditure surveys, most having only one survey per country. Now, 116 low- and middle-income countries are oftentimes using more than one HCES. In most of these countries, surveys are used every 3-5 years using the same sampling frame as the country's census, representing on average 7,000 to 8,000 households. Nepal has a Household

Consumption and Expenditure Survey called the Living Standards Survey. This survey has been used in 1995, 2000, 2003, and 2010. The Living Standards Survey gathers data on a number of criteria including perceptions of food security, dietary diversity, and means of food acquisition. An advantage of this survey is that it collects data on acquisition, whether food consumed in the household is produced at home through farming or gardening or whether that food is purchased. When combined with income data, this information provides insight into the percentage of household income spent on food, which is important when considering how price spikes or changes in household income might affect household food security. The 2010 Living Standards Survey sampling 7,020 households reported that an average of 61.5% of household expenditure went towards food purchases. The survey also found that the percentage of households reporting "less than adequate food" consumption had decreased from the 1995 survey, while those that reported "just adequate" and "more than adequate had increased" (see Table 5 below). In this survey, Nepal defined food security as "having enough food or enough resources to buy food." Thus, this definition ignores the utilization and stability component of food security. Additionally, 8% of households surveyed reported not being able to afford to eat what they normally would within the past thirty days, with an average food shortage of 6 out of the past 30 days. For these households, the survey collected data on the coping methods used. 68% borrowed money for food, 57% purchased food on credit, 51% relied on less expensive/preferred foods, 42% cut the sizes of their meals, and 33% reduced the frequency of their meals.

Table 5: Food Consumption Adequacy in Nepal

Description	Nepal Living Standards Survey		
	1995/96	2003/04	2010/11
Percentage of households reporting food consumption by degree of adequacy			
Less than adequate	50.9	31.2	15.7
Just adequate	47.3	66.7	82.0
More than adequate	1.8	2.1	2.3

Source: Nepal Living Standards Survey, 2011

This 2010 Nepal Living Standards Survey captured financial and physical access to food, as well as coping strategies that study participants used in times of food insecurity. Interestingly, the same survey collected anthropometric (height and weight) data, and in 2010 showed that 42% of children were stunted (defined as low height-for-age and a sign of chronic malnutrition) and 15% were severely stunted, yet only 15.7% of households were reporting “less than adequate consumption”. This suggests that there is a disconnect between appraisal of food insecurity and true food insecurity in this context, as subjective measures did not correlate with objective anthropometric data. Other studies have reported similar disconnects between subjective and objective measures of food insecurity (Migotto, Davis, Carletto, & Beegle, 2005; Coates et al. 2003). While Nepal used the Living Standards Survey as a proxy for food insecurity, they did not aggregate the economic access and food consumption adequacy data to create a more comprehensive indicator of food insecurity. Instead, these components were reported separately. Thus, it is not only important to measure multiple facets of food insecurity but also to have a composite score that takes them all into account.

Summary

The table below (Table 6) summarizes the seven different indicators, what they measure, the length of the surveys’ recall periods, whether or not the surveys are standardized, and whether or not these surveys have yet been used in Nepal. Because this study uses the Household Food Insecurity and Access Scale to collect data on food insecurity in Nepali households, this chart may serve as a helpful reference to see how the HFIAS compares to other indicators.

Table 6: Comparing Household Food Insecurity Indicators

Indicator	What does it measure?	Recall Period	Standardized vs. Must be adapted	Used in Nepal?
CSI	Coping Behaviors	7 days	Must be adapted	No
rCSI	Coping Behaviors	7 days	Standardized	No
FCS	Dietary Diversity	7 days	Must be adapted	Yes
HDDS	Dietary Diversity	24 hours	Standardized	No
HFIAS	Behaviors; Feelings of Anxiety	30 days	Standardized	Yes
HHS	Behaviors; Feelings of Anxiety	30 days	Standardized	No
HCES - LSS	Consumption; Acquisition	30 days	Standardized	Yes

CSI – Consumption Strategies Index, **rCSI** – Reduced Coping Strategies Index, **FCS** – Food Consumption Score, **HDDS** – Household Dietary Diversity Scale, **HFIAS** – Household Food Insecurity Access Scale, **HHS** – Household Hunger Scale, **HCES-LSS** – Household Consumption Expenditure Survey-Living Standards Survey

A diversity of scales that can be used to measure household food insecurity clearly exists, but there is still a lack of an accepted standard, easy-to-use, reliable method. The international research community is working to develop indicators that can be used on their own, but there is still no standard “best” method (Webb et al., 2006). This research is important to understanding food insecurity and the ways in which it manifests at the household level, as well as to informing future food policy and interventions for food insecure households. We must strive for a measurement that measures all four components of food insecurity – access, availability, utilization, and sustainability – in a manner that is cheap, easy-to-use, efficient, and effective.

Chapter 2

Iron Deficiency: Prevalence, Consequences, Treatments

Iron is the fourth most abundant element on earth, and it is vitally important for the functioning of almost all living organisms. In humans, iron is required for oxygen transport as a component of hemoglobin, oxygen storage as a component of myoglobin, DNA synthesis, ATP production, and oxidative and reductive processes as part of redox enzymes (Insel, Ross, McMahon, & Bernstein, 2014; Clark, 2014). Despite its abundance, iron deficiency is the most prevalent nutrient deficiency worldwide (WHO, 2011). Iron deficiency often manifests itself as anemia, and while there are other causes for anemia, iron deficiency is predicted to cause 50% of anemia cases worldwide (WHO, 2011). Approximately 800 million people worldwide are affected by anemia, including 496 million non-pregnant women, 273 million pregnant women, and 32 million children worldwide (Stevens et al., 2013; WHO, 2011). There are major health consequences associated with anemia including compromised physical and cognitive development, poor pregnancy outcomes, increased risk of mortality in children, and diminished productivity in adults (Clark, 2008).

This chapter will discuss the foods in which iron is found, factors affecting iron absorption, the metabolism of iron in the body, and the consequences of iron deficiency and iron deficiency anemia with a focus on women and children. The end of this chapter will focus on Nepal specifically, including the prevalence and causes of iron deficiency there, as well as the efficacy of interventions and treatments that have been implemented in Nepal.

Dietary Iron Sources

Dietary iron is found in both plant and animal food sources, and there are two types of dietary iron found within these foods. The first, heme iron, is only found in animal sources because it exists as a part of hemoglobin and myoglobin in animal tissue (Insel, Ross, McMahon, & Bernstein, 2014). The other type, non-heme iron, is found in plant sources and dairy products, as well as animal sources. Approximately 40% of the iron found in animal sources is heme iron, while the remaining 60% is non-heme iron (Insel, Ross, McMahon, & Bernstein, 2014). All of the iron from plant sources and dairy products is non-heme iron. Generally, the body absorbs 15-35% of heme iron consumed, while only 2-20% of non-heme is absorbed (Insel, Ross, McMahon, & Bernstein, 2014). Because heme iron is more efficiently absorbed by the body than non-heme, both the amount of iron-rich foods one consumes and the type of iron consumed are important to maintaining sufficient iron status. Below is a table of heme and non-heme iron sources.

Table 7: Heme & Non-Heme Iron Sources

Heme Iron Food Sources	Milligrams per serving	Non-heme Iron Food Sources	Milligrams per serving
Oysters, 3 oz.	8	Fortified breakfast cereals with 100% DV for iron	18
Beef liver, 3 oz.	5	White beans, 1 cup	8
Beef, 3 oz.	2	Lentils, ½ cup	3
Sardines, 3 oz.	2	Spinach, boiled, ½ cup	3
Chicken, 3 oz.	1	Chickpeas, ½ cup	2
Egg, 1 large	1	Stewed tomatoes, ½ cup	2

Source: NIH, 2015

Once ingested, the amount of iron in the body is regulated by gastrointestinal absorption. There are a number of factors that affect the absorption of iron including an individual's iron status, diet composition, and health status, which will be discussed in the next section.

Factors Impacting Iron Absorption

There are three main factors that impact the absorption of iron in the body. These include an individual's iron status (iron deficient vs. sufficient), diet composition, and disease status.

The effect of iron status on iron absorption

An inverse relationship exists between an individual's iron status and the amount of iron the body absorbs from the diet. If an individual is iron deficient, the body absorbs more iron from the diet than it would if the individual were iron sufficient. In a study on iron absorption in Indian women, women who were iron deficient absorbed 17.5% of the iron from the meals provided by the study, whereas the iron sufficient control subjects absorbed only 7.0% (Thankachan et al., 2008). Another study on iron absorption in Indian women found that absorption from a rice-based meal was on average three times higher in the iron deficient group than in the iron replete group (Kalasuramath, Kurpad, & Thankachan, 2013). Thus, when the body requires more iron, iron absorption is upregulated. One important note here is that only non-heme iron absorption may be upregulated; it does not appear that the absorption of heme iron can be upregulated when body demand is high (Björn-Rasmussen, 1983; West & Oates, 2008), likely because of the extra steps involved in the metabolism of heme iron into the enterocyte. This will be discussed in the "Metabolism of Iron" section. Regardless, the differential absorption of non-heme iron based on iron status can likely be explained by the peptide hepcidin and its role in the regulation of iron transport from iron-exporting tissues to the blood plasma (Ganz, 2006). Hepcidin blocks the efflux of iron into the blood plasma by inducing the degradation of ferroportin, the sole iron exporter. Hepcidin synthesis is thus downregulated when an individual is iron deficient, preventing the degradation of ferroportin and allowing iron to be exported to the plasma (Ganz, 2006). This mechanism will also be explained further in the "Metabolism of Iron" section.

The effect of diet composition on iron absorption

The amount of iron consumed in the diet clearly impacts the amount that the body absorbs. The more iron one consumes, the more the body is able to absorb. Typically, the body loses 1-2 mg of iron per day from the sloughing of intestinal cells, blood losses, and feces (Anderson, Darsham, Wilkins, & Frazer, 2007). This iron must be replaced by the diet, and because only some of the iron in the diet gets absorbed (15-35% from heme, 2-20% from non-heme), the recommended daily allowances (RDA) of iron ranges from 7 mg to 27 mg, depending on age, sex, and physiological state (pregnancy, for example) (NIH, 2015). The table below produced by the National Institutes of Health shows the RDAs for iron. Note that RDAs during pregnancy are significantly higher. This will be discussed in the "Consequences of Iron Deficiency" section.

Table 8: Recommended Daily Allowances for Iron

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	0.27 mg*	0.27 mg*		
7-12 months	11 mg	11 mg		
1-3 years	7 mg	7 mg		
4-8 years	10 mg	10 mg		
9-13 years	8 mg	8 mg		
14-18 years	11 mg	15 mg	27 mg	10 mg
19-50 years	8 mg	18 mg	27 mg	9 mg
51+ years	8 mg	8 mg		

* Adequate Intake (AI)

Source: NIH 2015

Other nutrients found in the diet can affect the bioavailability of iron by either enhancing or inhibiting its absorption. The absorption of both heme and non-heme iron are enhanced by the consumption of meat, fish, and poultry (Hallberg, 1981), and the absorption of non-heme iron is enhanced by ascorbic acid, also known as vitamin C (NIH, 2015). The absorption of both heme iron and nonheme iron is inhibited by calcium, while non-heme iron is also inhibited by phytates (found in grains and beans), polyphenols (found in cereals, legumes, and tea), tannins (found in tea), and oxalates (found in dark leafy greens) (NIH, 2015). Thus, a diet rich in heme iron from animal sources and vitamin C often delivers more bioavailable iron than vegetarian diets. This has major implications for the prevalence of iron deficiency and iron deficiency anemia in the developing world, as oftentimes diets in the developing world contain less meat (if they are not vegetarian) and more grains, beans, and legumes. This will be discussed further in the “Why iron deficiency is more prevalent in the developing world” section.

The effect of parasitic infections on iron absorption

Within much of the developing world, parasitic infections are a leading cause of iron deficiency. Helminth infections can cause tears in the intestinal mucosal lining, which leads to blood loss, and many helminths also feed off of human blood (Hesham, Edariah, & Norhayati, 2004; Stoltzfus, Dreyfuss, Chwaya, & Albonico, 1997). Additionally, malaria-causing *Plasmodium* parasites, which affect millions of people living in the developing world, destroy red blood cells thus decrease circulating blood iron (Gyorkos & Gilbert, 2014; WHO, 2015). Provided the high global prevalence and direct iron deficiency causal pathways, parasitic infections are a major risk factor in the development of iron deficiency.

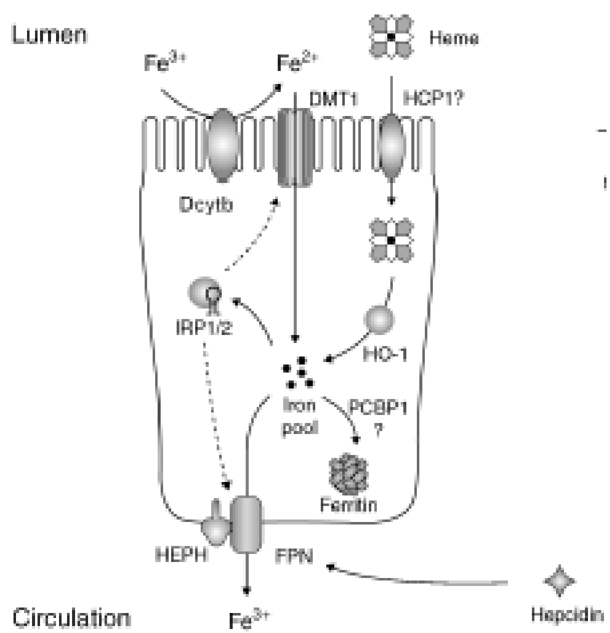
The next section will cover the metabolism of iron in the body to both demonstrate its complexity and its importance in a number of structures and functions within the body.

Metabolism of iron in the body

Iron is a labile element, meaning it can readily change oxidation states or valence. Iron can exist in its reduced state (Fe^{2+}) or its oxidized state (Fe^{3+}) by losing or gaining electrons, respectively. Because of this duality, iron participates in a number of oxidation-reduction (redox) reactions, including those involved in cellular respiration, metabolism, and DNA synthesis (Insel, Ross, McMahon, & Bernstein, 2014). Iron plays an important role in the body as a necessary component for the proper structure and function of hemoglobin, myoglobin, cytochromes, enzymes, and other proteins (Insel, Ross, McMahon, & Bernstein, 2014). However, the capability of iron to participate in redox reactions can have negative consequences for the body when unregulated. In excess, free iron is able to produce free radicals, which are known to cause DNA and tissue damage (Anderson, Darsham, Wilkins, & Frazer, 2007). Thus, iron absorption and metabolism must be tightly controlled processes.

Non-heme iron absorption

Iron absorption occurs at the epithelium of the proximal small intestine. Non-heme iron crosses at the apical border of enterocytes through the ferrous iron (Fe2+) divalent metal ion transporter 1 (DMT1). However, iron is usually in its ferric (Fe3+) state in the diet and in the body. Thus, iron must first be reduced by the enzyme reductase duodenal cytochrome B (DcytB) before it can be taken up through DMT1. Once in the enterocyte, if the body's demand for iron is low, the iron stays in the enterocyte and is stored as ferritin. If the iron stored is not mobilized due to continual low demand, it will likely be lost within a few days when enterocytes are sloughed. If the body requires iron, the iron export protein ferroportin will bind the iron ions within the enterocytes and transport them across the basolateral



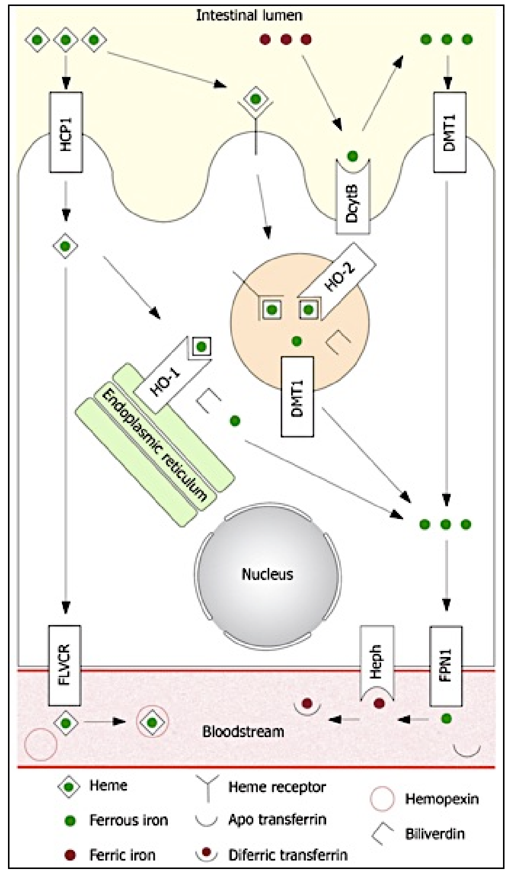
Source: Anderson et al., 2009

Figure 5: Non-heme Iron Absorption

membrane and into circulation. Before entering circulation, iron must first be converted back to its ferric state by hephaestin. Once in circulation, iron binds to plasma apo transferrin for transportation (Anderson, Frazer, & McLaren, 2009). This process is shown in Figure 5.

Heme Iron Absorption

Heme iron absorption also takes place at the epithelium of the proximal small intestine, although the mechanism by which this occurs is not well understood. There are two theories for how heme iron is taken up by enterocytes (West & Oates, 2008). The first theory is receptor-mediated endocytosis, where heme iron enters the enterocyte by binding to a receptor on the cell membrane and then is internalized by a membrane vesicle. Once inside the cell, it is hypothesized that heme iron within the vesicle is degraded by heme oxygenase 2 (HO-2) into ferrous iron, then bound to DMT1, and either stored within the cell as ferritin or bound to ferroportin for export into circulation. Whether it stays within the cell or is exported is dependent on body demand.



Source: West & Oates, 2008

Figure 6: Heme Iron Absorption

The second theory is that heme iron enters circulation directly without being converted to its ferrous state. This is predicted to occur in one of two ways. First, heme may enter the enterocyte intact via heme carrier protein 1 (HCP1) and leave intact via FLVCR, a cell surface heme exporter (Khan & Quigley, 2013). Once outside the cell, heme is attached to hemopexin (an extracellular heme-binding protein) in circulation (Khan & Quigley, 2013). Alternatively, heme iron may be broken down into non-heme iron by heme oxygenase 1 (HO-1) on the endopasmic reticulum within the cell. Then, the catabolized heme iron would either be stored as ferritin, or bound to ferroportin for export into the bloodstream. These two processes are demonstrated in Figure 6.

Mediators of Iron Absorption

Hepcidin is an important mediator of iron absorption. Hepcidin is an iron homeostasis hormone produced in the liver (Anderson, Darshan, Wilkins, & Frazer, 2007) that detects body iron levels and responds to external and internal iron content cues (Anderson, Frazer, & McLaren, 2009). Hepcidin acts by binding to ferroportin, internalizing it and degrading it. Because of ferroportin’s central role in mobilizing iron from the intracellular enterocyte to extracellular circulation, hepcidin effectively decreases the export of iron into the bloodstream. Hepcidin also alters DMT1 levels by altering the synthesis of the divalent metal ion transporter. This occurs via translation of DMT1 from mRNA to protein. The mRNA for DMT1 has an iron responsive element (IRE) where iron regulatory proteins (IRP1/2) bind to and effectively knockout the expression of DMT1. Because DMT1 transports iron into the enterocyte, downregulation of DMT1 prevents iron from being taken up into the enterocyte for absorption into the body. Thus, hepcidin is upregulated when iron is sufficient to protect the body from absorbing excess iron. Additionally, hepcidin is downregulated when the body is iron deficient to allow greater absorption.

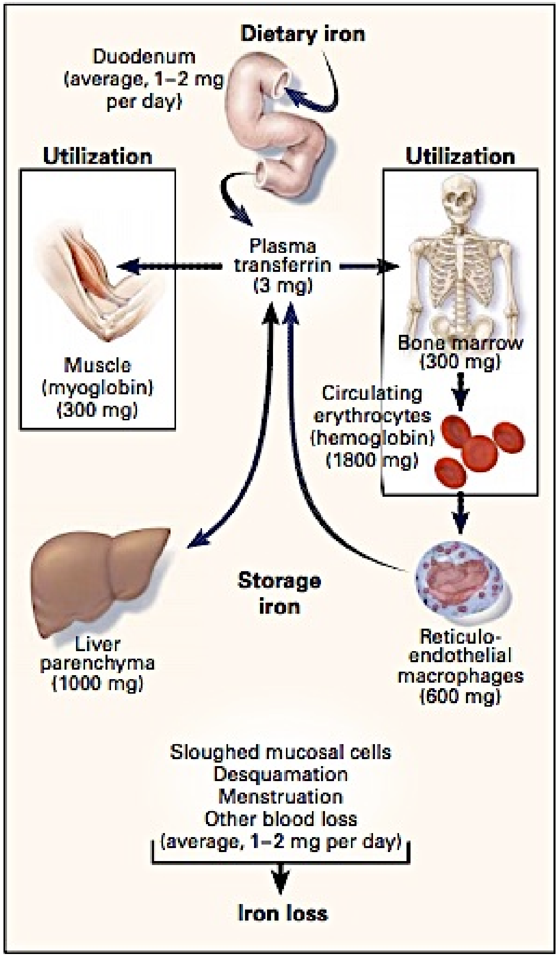
Other important players in the metabolism of iron are also regulated by mRNA IRE-IRP systems including DMT1 and ferroportin (Mackenzie, Iwasaki, & Tsuji, 2008). DMT1 is normally expressed at low levels, but during times of iron deficiency, DMT1 is expressed and appears at much higher levels. This relationship is also true for ferroportin, a transmembrane protein and the primary iron exporter. Ferroportin is also expressed in reticuloendothelial macrophages, which phagocytize senescent red blood cells, recycling the iron after red blood cells are broken down (Mackenzie, Iwasaki, & Tsuji, 2008).

Uptake of iron in non-intestinal cells

While iron absorption occurs within enterocytes, all cells in the body require iron for proper functioning (Mackenzie, Iwasaki, & Tsuji, 2008). In non-intestinal cells, iron is taken up by receptor-mediated endocytosis after it has been released into circulation from the enterocytes. Iron that is in circulation is bound to transferrin, and there are two ferric iron ions bound to each transferrin molecule. For iron to be taken up by cells, it must first bind to transferrin receptor (TfR) on the cell surface. Once bound to TfR, the entire TfR-Tf-Fe3+ complex is endocytosed. Inside the cell, the low pH in the endosome causes the dissociation of ferric iron from the complex, the iron ions are then reduced to the ferrous state, and ferrous ions are transported into the cytoplasm through DMT1. The TfR-Tf complex is recycled back to the cell membrane (Hentze, Muckenthaler, Galy, & Camaschella, 2010). Once in the non-intestinal cell, iron can be used for a number of functions including DNA synthesis, storage of iron within muscles as myoglobin, and ATP production as part of cytochromes, flavoproteins, and other mitochondrial compounds (Scrimshaw, 1984). Transferrin receptor levels are also controlled by IRE/IRP systems that regulate the transcription of TfR-encoding mRNA based on iron levels within the cell, providing another mechanism for the regulation of iron absorption. If and when iron is exported from non-intestinal cells, the ferrous iron must be oxidized before entering circulation. Because hephaestin is only expressed in enterocytes, ceruloplasmin is the ferroxidase that converts ferrous iron into ferric iron before entering circulation from non-intestinal cells (Hentze, Muckenthaler, Galy, & Camaschella, 2010).

Ferritin is the major protein involved in iron storage. Ferritin sequesters potentially harmful excess iron (up to 4,500 iron atoms) and stores iron for release in times of need. Ferritin is located in all cells throughout the body, including the cytoplasm, nucleus, and mitochondria of cells of many different tissues. When the body is low in iron and iron stores must be mobilized, ferritin is tagged for degradation through either lysosomal or proteasomal pathways (Mackenzie, Iwasaki, & Tsuji, 2008). As with TfR, IRE/IRP systems regulate ferritin post-transcriptionally by inhibiting mRNA translation in iron deplete cells and promoting translation in iron replete cells (Hentze, Muckenthaler, Galy, & Camaschella, 2010).

Where is iron found in the body?



Source: Andrews, 1999

Figure 7: Iron in the Body

Depending on age, sex, and iron status, the body will contain 0-15 mg of iron per kg of body weight. For a 55 kg woman, this is 2,300 mg. About 88% of iron in the body is found in functional compounds, including hemoglobin, myoglobin, and enzymes. About 11% is found in ferritin and hemosiderin stores, and the remaining 1% is found in transferrin (Bodnar, Scanlon, & Cogswell, 1999). Most body iron is taken up in the bone marrow for incorporation into hemoglobin in developing erythrocytes (Anderson, Darshan, Wilkins, & Frazer, 2007). When erythrocytes are old or damaged, cells in the reticuloendothelial system will break them down and recirculate the iron (as shown in Figure 7). About 25 mg of iron is recycled each day, which is mostly dedicated to the synthesis of hemoglobin (Hentze, Muckenthaler, Galy, & Camaschella, 2010).

Additionally, 1-2 mg of iron per day are lost through menstruation, growth, pregnancy, lactation, as well as through basal losses including feces, urine, sweat, hair, and nails (Anderson, Darshan, Wilkins, & Frazer, 2007). These losses inform the recommended daily allowances for iron established by the government. Because many causes for iron loss are specific to women, women are at greater risk for iron deficiency, which will be discussed in the next section.

Consequences of Iron Deficiency

When an individual does not have enough iron in their body, they are said to be iron deficient. Iron deficiency can lead to anemia, a condition characterized by having less than the normal number of red blood cells *or* less than the normal quantity of hemoglobin within red blood cells. When caused by an iron deficiency, red blood cells are microcytic (Massey, 1992). The Venn Diagram below (Figure 8) indicates that iron deficiency and anemia overlap, but are different conditions.

The 2013 WHO Global Burden of Disease Project found that iron deficiency anemia was the leading cause of Disability-Adjusted Life Years (DALYs) among children and adolescents, accounting for 17,549,206 DALYs among children and adolescents aged 5- to 19-years. Iron deficiency anemia was also cited as the leading cause of years lived with disability (YLDs) among children and adolescents (Global Burden of Disease Pediatrics Collaboration, 2016). Not only does iron deficiency have implications for the health and wellbeing of nations, it also has a serious impact on these nations' economies as a result of death and decreased productive work capacity among citizens. One study examining iron deficiency in ten different developing countries estimates that GDP losses from iron deficiency may be as large as four percent (Horton & Ross, 2003).

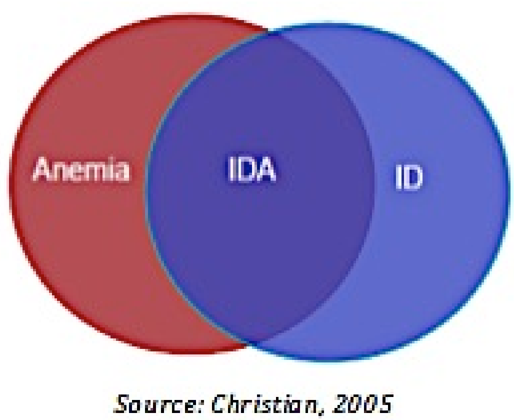
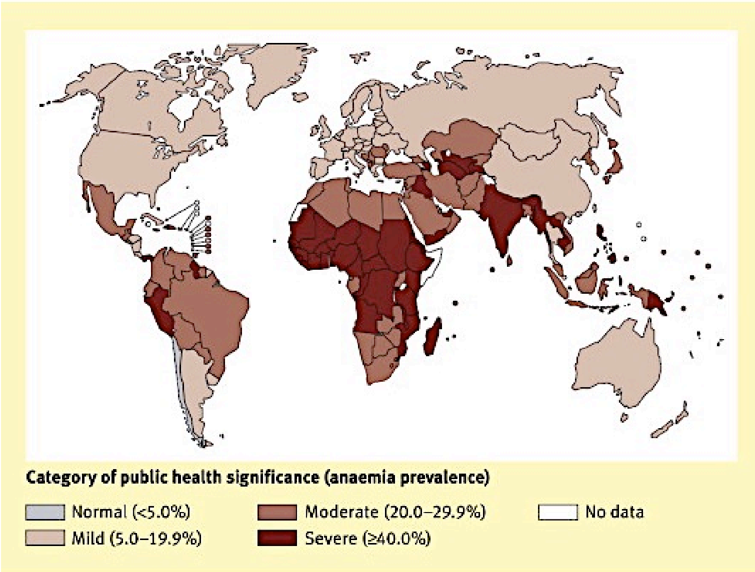


Figure 8: Overlap of Iron Deficiency and Anemia

If an individual is iron deficient, they are likely to experience reduced endurance and energy levels, impaired cognitive and physical function, difficulty controlling behavior and emotion, impaired temperature regulation, impaired immune response, and pregnancy complications including low birth weight and maternal and perinatal mortality (Jåuregui-Lobera, 2014; Clark, 2008; Stoltzfus, 2003). If iron deficiency is very severe, it can cause death, but in many cases, iron deficiency is an important risk factor for morbidity and mortality (Stoltzfus, 2003). For example, iron deficiency can lead to maternal mortality by increasing the risk of cardiac arrest during birth due to impaired muscle function (Stoltzfus, 2003). Those affected by iron deficiency, however, do not often recognize the negative side effects because it is a chronic illness where decline in cognitive and physical function is gradual. In places with high prevalence, it might be considered normal to experience some of the major symptoms of iron deficiencies.

Why iron deficiency is more prevalent in the developing world

The nutrients that enhance or inhibit iron absorption can help to explain the high prevalence of iron deficiency in the developing world. It should be noted, however, that iron deficiency also significantly impacts industrialized countries. In fact, it is the only significantly prevalent mineral deficiency in industrialized countries (Pettit, Rowley, & Brown, 2011). The map to the right shows the prevalence of anemia worldwide. The highest prevalence, shown in brown, is found across South America, Africa, and Southeast Asia.



Source: Pettit, Rowley, & Brown, 2011

Figure 9: Global Anemia Prevalence

While iron deficiency is the major cause of anemia, the other causes of anemia include hookworm infections, malaria infections, vitamin A, vitamin B12, folate, and riboflavin deficiencies, as well as chronic infections and inherited disorders (WHO, 2011a). Across the world regions with high anemia prevalence, we also see a high burden of many of these other causes, including hookworm infections, malaria, and other micronutrient deficiencies.

Considering the major causes of iron deficiency, the explanation for such a high prevalence of iron deficiency across South America, Sub-Saharan Africa, and Southeast Asia become more evident. First, the amount of iron consumed in the diet is a major factor. In many parts of the developing world, malnutrition is a serious problem, where people simply are not consuming enough food to sustain a healthy life, which is evidenced by higher rates of stunting and wasting among developing countries. Where people are not consuming enough, it is less likely that they are getting enough iron from the food that they are consuming. Moreover, the standard diet in much of the developing world is centered on rice and beans, two foods that are full of iron-inhibiting fiber and phytates. Tea is a very common drink across Africa and Southeast Asia, and the tannins present in tea also inhibit iron absorption, especially when consumed during meal times. Additionally, because meat and animal products are typically a luxury in poorer regions, these iron-rich foods are not consumed often, if at all. For example, many Hindus in India are vegetarian, and thus rarely consume heme iron. Lastly, parasitic infections are common in many of the world regions where iron deficiency is a public health concern. Parasitic infections not only contribute to the development of iron deficiency in these contexts, but they also can complicate the treatment of iron deficiency. Thus, when addressing iron deficiency in the developing world, it is important to consider the specific regional concerns that further complicate the etiology of iron deficiency. The next section will discuss the stages of iron deficiency and the biomarkers that help us identify those stages in human beings to frame a further discussion on the treatment of iron deficiency in the developing world.

Measuring iron status in the body

There are three stages of iron deficiency with each successive stage representing increasing severity. The first stage of iron deficiency is the depletion of iron stores, represented by a decline in serum ferritin concentration (Scrimshaw, 1984). Under ideal conditions, a serum ferritin level of less than 12 μg/L is indicative of a depletion of iron stores (Hambridge, 2003). However, serum ferritin is an acute phase protein that elevates in response to inflammation, so in many contexts where inflammation is prevalent from acute and/or chronic disease, the cut-off may be raised to 30 μg/L (WHO, 2011b). Another way to adjust for inflammation is to also measure C-reactive protein (CRP) and/or α-1-acid glycoprotein (AGP) and apply a correction factor to the serum ferritin measurements (Thurnham et al., 2010).

Transferrin receptor (TfR) can be measured to detect early functional iron deficiency as an indicator of cells trying to get more iron. TfR expression increases in response to iron deficiency to provide more opportunities for iron binding. The normal range for TfR in iron replete individuals is 5-8 mg/L, and thus, 8.3 mg/L or above is indicative of depleted iron stores (Gropper, Smith, & Groff, 2009). Similarly, total iron-binding capacity (TIBC) is another biomarker that is elevated in individuals with early functional iron deficiency. TIBC measures transferrin after saturation of all iron-binding sites (CDC, 2012); in iron deficient individuals, TIBC is increased when less iron is around to bind to transferrin, leaving TfR empty or only bound to one molecule. A normal TIBC would be 250-400 g/dL, and any reading above 400 g/dL is indicative of deficiency (Gropper, Smith, & Groff, 2009). Erythrocyte protoporphyrin (EPP) and serum iron are two other useful biomarkers for assessing iron status. An EPP score greater than 70 μg/dL of red blood cells for children under 5 years of age and greater than 80 μg/dL of red blood cells for those over five years is considered iron deficient (WHO, 2004). A serum iron score of less than 60 μg/dL is also indicative of iron deficiency (US National Library of Medicine, 2014a). Transferrin saturation can also be measured to detect early functional iron deficiency, expressed as a ratio of serum iron to TIBC (Scrimshaw, 1984). Transferrin saturation is often expressed as a percentage, where 15-30% transferrin saturation is the normal range. A score below 15% indicates early functional iron deficiency (Hambridge, 2003).

The third stage, late functional iron deficiency, occurs when the production of essential iron compounds, such as hemoglobin, are restricted (Scrimshaw, 1984). Hemoglobin of less than 11 g/dL represents anemia in children and pregnant women, and a hemoglobin of less than 12 g/dL represents anemia in adults. Because anemia can be caused by a number of other diseases and deficiencies, hemoglobin concentrations do not necessarily reflect iron deficiency anemia. Mean corpuscular volume (MCV) is a measurement of the volume of a red blood cell and can also be measured to assess late functional iron deficiency. MCV is calculated by dividing hematocrit (the volume percentage of red blood cells in blood) by red blood cell count. Iron deficiency anemia often causes microcytic red blood cells, so a low (<80 fL) MCV can indicate iron deficiency (US National Library of Medicine, 2014b).

Iron deficiency in Nepal

While the prevalence of anemia has been steadily falling in Nepal, it still remains high. In 2011, 50.8% of children under 5 years of age, 35.6% of non-pregnant women, and 44.3% of pregnant women were anemic (World Bank, 2011). While anemia has causes besides iron deficiency, data on iron deficiency specifically in Nepal is sparse.

In a study examining the risk factors for anemia among pregnant Nepali women living in the southeastern plains region, iron deficiency was found to be an important risk factor for the development of anemia, but it accounted for less than half (23.7%) of the anemia among participants (Makoul et al., 2012). This may be attributed to the recent increase in iron supplement coverage in Nepal. Other risk factors noted in the study included hookworm infections and vitamin A deficiency. This contribution of iron deficiency to anemia is lower than the expected 50% and is consistent with other findings where iron deficiency was present among less than half of the anemic rural pregnant Nepali women sampled (Jiang et al., 2005).

In contrast, a study of rural pregnant Nepali women found that 73% were anemic, with 88% of the anemia associated with iron deficiency (Dreyfuss et al., 2000). Additionally, of 500 non-pregnant women of reproductive age in urban Bhaktapur, Nepal, half of the anemia cases were attributable to iron deficiency (Chandyo et al., 2007). Another study of urban pregnant women found that a third were moderately anemic, and half of the severely anemic women were iron deficient (Bondevik et al., 2000).

In a study of 4- to 17-month old rural Nepali children, 58% of children were anemic and 75% of their anemia was caused by iron deficiency (Siegel et al., 2005). Another major study in 1,232 children in urban Bhaktapur, Nepal, aged 6- to 35-months, found that 52% were anemic and one in three were iron deficient, while 16% of children had iron deficiency anemia (Chandyo, Ulak, Adhikari, Sommerfelt, & Strand, 2015). This finding is contradictory to Siegel et al., as less than half of the anemia was attributable to iron deficiency.

Despite the absence of clear, population-level data on iron deficiency and its related anemia in Nepal, it is evident that iron deficiency is still a major public health concern. However, Nepal has made a lot of progress in the past decade in providing iron supplements to pregnant women to prevent anemia, premature delivery, maternal and infant mortality, and low birth weight infants. In 2003, Nepal, with the support of the Micronutrient Initiative and World Health Organization, launched the Iron Intensification Project in five Nepali districts. Over the next nine years, Nepal scaled up that effort to reach 74 out of 75 total districts in the country. The percent of pregnant women taking iron folic acid supplements increased 23% in 2001 to 80% in 2011. Anemia prevalence among pregnant women decreased from 75% in 1998 to 48% in 2011 (Upreti, Subedi, Paudyal, & Maharjan, 2014). While there have been huge improvements, there is still much progress to be made. Nearly half of pregnant women having anemia is still too high, and child anemia remains high, as well.

Chapter 3

Food Insecurity and Iron Deficiency in the Developing World

One might predict that household food insecurity and iron deficiency would be related. If a household is food insecure, they may not have enough food in the house or enough money to buy food, and the food that they do have may not be adequate to support a healthy, well-balanced diet. If any one of these conditions are true, it seems logical that iron deficiency might follow, as the primary cause of iron deficiency is inadequate consumption of iron. Foods with the most bioavailable heme iron are generally expensive meat and animal products, and cheaper foods are often filled with fiber and phytates that inhibit the absorption of iron, like rice and beans. The research, however, has been sparse and inconclusive, with many studies suggesting that there is no relationship between food insecurity and iron deficiency.

Studies are examining food insecurity and anemia as a proxy for iron deficiency but few have looked at indicators of iron deficiency specifically. Of primary interest are studies using the Household Food Insecurity and Access Scale (HFIAS), as that was the food insecurity indicator used in Bhaktapur, Nepal that will be examined in this thesis.

In Southeast Asia, three studies have examined food insecurity using HFIAS and anemia using hemoglobin – one in Cambodia and two in Nepal. McDonald et al. (2005) found that household food insecurity was associated with maternal, but not child, anemia in rural Cambodia. In this study, 900 households were surveyed using the HFIAS, and hemoglobin was measured in each non-pregnant woman and children under 5 years of age. While they observed a high prevalence of food insecurity (81.6%) and the mean child hemoglobin was 10.5±14 g/dL, the two did not significantly correlate. However, mothers living in food insecure households were 1.73-1.79 times more likely to have anemia than mothers living in food secure households.

Osei et al. (2010) also found no association between household food insecurity and child anemia. Their sample was made up of 368 children ages 6-24 months from families living in rural south central Nepal. A shortened 5-question version of the HFIAS was administered to capture food insecurity and hemoglobin was measured for estimating anemia. While the study found that children from food insecure households were more likely to be stunted or wasted, two indicators of malnutrition, they found no significant relationship between food insecurity and anemia. Another study in Nepal used Nepal's Demographic Household Survey census data to explore the relationship between food insecurity and anemia. This survey had both HFIAS and hemoglobin data, and analyses revealed no association between the two (Nisar, Anwar, & Nisar, 2013).

Two additional studies conducted in India and Iran have examined food insecurity using HFIAS and iron deficiency anemia using both hemoglobin and specific iron indicators. Salarkia et al. (2015) examined household food insecurity and iron deficiency specifically, by measuring HFIAS and both hemoglobin and serum ferritin in a group of 6-24 month-old Iranian children. More than half of the households were food insecure, and the prevalence of child anemia, iron deficiency, and iron deficiency anemia were 29.1, 12.2, and 4.8%, respectively. There was no association between food insecurity and anemia or food insecurity and iron deficiency. However, 80% of the children in the study had received iron supplements, so perhaps a variable that might confound a potential relationship between food insecurity and iron deficiency would be the provision of iron supplements. If children are receiving and inadequate quantity and/or quality of food, taking iron supplements could ameliorate any expected deficiency.

Pasricha et al. (2010) found a significant correlation between food insecurity and anemia in rural Indian children aged 2-23 months, but the predictor variable was anemia and the outcome was food insecurity. HFIAS was used as a measure of food insecurity and hemoglobin and ferritin were used to measure anemia and iron deficiency, respectively. More than half of the families in this study were food insecure (52.7%), 75.3% of children were anemic, and 61.9% of children were iron deficient.

Additionally, 57% of food insecure households had anemic children. Children with anemia were more likely to be food insecure than children without anemia (OR: 2.2, $p<0.005$). However, no significant relationship was found between household food insecurity and iron deficiency (measured by ferritin levels). Children's ferritin levels were only associated with maternal hemoglobin and CRP in this study.

Another study explored the risk factors of anemia and iron deficiency in Nepali children using a sample of 569 4- to 17-month olds but did not use HFIAS as a measure of food insecurity. Instead a dietary diversity questionnaire and various socioeconomic indicators were used as proxies for household food insecurity. After measuring hemoglobin and erythrocyte protoporphyrin (EP), 58% of children were anemic, and 43% of children were iron deficient anemic. Thus, 74% of the anemia in this group was attributable to iron deficiency. The only significant risk factors for anemia and iron deficiency anemia were age and caste status, not food insecurity. The younger, low-caste children were at highest risk for both anemia and IDA (Siegel et al., 2006).

This thesis explores the relationship between household food insecurity and iron status by measuring HFIAS, ferritin, transferrin receptor, and hemoglobin in a cohort of Nepali children living in Bhaktapur, Nepal. Understanding this potential relationship is important because it can help to identify households with children at risk for iron deficiency. If a strong relationship is detected, the HFIAS could be a simple tool to assess food insecure households and create targeted iron supplementation programs. If a strong relationship is not observed, it will be important to ensure that the HFIAS is accurately assessing food insecurity in this population before concluding that food insecurity is unrelated to iron deficiency in this setting. Further research should then identify if there are other underlying causes for iron deficiency besides inadequate iron consumption from the diet (e.g. hookworm infections, chronic inflammation, etc.) or if the HFIAS tool is insufficient in capturing household food insecurity.

Chapter 4

Food Insecurity and Iron Deficiency in a Cohort of Nepali Children

Background

Recent research has begun to examine the relationship between iron status and food insecurity in the developing world, but the data is sparse and inconclusive. Six studies in Southeast Asia have studied the HFIAS as it relates to anemia and iron deficiency, and only one found a significant relationship between food insecurity and anemia (Pasricha et al., 2010). Although many of these studies found no relationship, most were measuring food insecurity as it relates to anemia. While iron deficiency is a major cause of anemia, there are others, some unrelated to food (e.g. hookworms, hemoglobinopathies, etc.). In this study, the relationships between scores on the Household Food Insecurity and Access Scale and concentrations of ferritin, transferrin receptor, and hemoglobin were assessed.

The primary objective of this study was to determine the relationship between household food insecurity and iron deficiency in Bhaktapur, Nepal. To this end, our hypothesis was that child food insecurity will predict iron deficiency, such that children coming from the most food insecure households will exhibit iron deficiency more often than those coming from food secure households. To test this hypothesis, household food insecurity and blood iron markers (ferritin, transferrin receptor, and hemoglobin) were analyzed from a cohort of 240 children living in semi-urban Bhaktapur, Nepal from 0 to 24 months of age. The secondary objective of this study was to assess how well the Household Food Insecurity Access Scale (HFIAS) correlated with other child health measures, including child growth indicators, nutritional adequacy, and socioeconomic status.

Study Population

This study examines Nepal data from the larger Malnutrition and Enteric Infections: Consequences for Child Health and Development (MAL-ED) Network cohort study that spans eight different field sites in eight different countries. In Bhaktapur, Nepal, 240 children were followed longitudinally from 0 to 24 months of age. The inclusion criteria were:

1. Healthy infants enrolled within 17 days of birth
2. Caregiver report that they had no plans to move out of the catchment area for at least 6 months following enrollment in the study
3. Willingness of caregiver to be visited in the home twice weekly

The exclusion criteria were any of the following:

1. The family had plans to move out of the catchment area for >30 consecutive days during the first 6 months of follow-up
2. The mother was under 16 years of age
3. The mother had another child already enrolled in the MAL-ED cohort study.
4. The child was not a singleton (ie, twins, triplets)
5. The infant had any of the following indications of serious disease: a. Hospitalization for something other than a typical healthy birth; b. Severe or chronic condition diagnosed by a medical doctor (eg, neonatal disorder; renal, liver, lung, and/ or heart disease; congenital conditions); or c. Enteropathies diagnosed by a medical doctor
6. The child's guardian failed to provide signed informed consent
7. Weight at birth or enrollment was <1500 g

Prior to enrollment, a census of Bhaktapur was performed to assess the number of women of reproductive age and the number of children under 5 years of age living there. This census included information on demographic and socioeconomic characteristics of the Bhaktapur region. Additionally, as a pilot of the MAL-ED study, researchers surveyed a sample of 100 households in Bhaktapur where children 24-36 months of age lived. This survey included information on food security and anthropometry. Table 5 summarizes the characteristics of the Bhaktapur site using the census data and the pilot study data. In the context of this thesis, it is interesting to note that 73% of households reported food security, yet 42% of children age 24-36 months were stunted (height-for-age Z <-2) in this population.

Table 9: Bhaktapur Demographic and Socioeconomic Characteristics

Indicator	Prevalence
Food secure (self-described)*	73%*
Stunting*	42%*
Literacy, heads of household	67%
Mean years of schooling, heads of household (1-18)	5.8
Literacy, mothers	94%
Tapped/piped drinking water	98%
Water treatment before drinking	47%
Electricity	100%
Heating	46%
Toilet facilities	99%
Owns a mobile phone	99%
Owns a television	93%
Owns a computer	27%
Owns a refrigerator	26%
Owns agricultural land	66%
Owns separate kitchen	70%

***Data from the MAL-ED Pilot Study*

Methods

While MAL-ED is an extensive study collecting a wealth of data across multiple field sites, only the methods for collecting data relevant to this analysis will be included here. The complete study design can be found in the November 2014 issue of Clinical Infectious Diseases, Supplement 4 (MAL-ED Network Investigators, 2014). My specific role in this project has been analyzing the food insecurity, blood iron, and nutrient intake data in a new way; however, I played no role in developing the initial study design or collecting the data. The MAL-ED research team in Nepal collected the data that I am analyzing for this thesis.

Anthropometry

Once enrolled in the MAL-ED study, each child's date of birth, sex, and birth weight, current length and weight, as well as information about breastfeeding initiation was recorded. Anthropometric measures (child's length, weight, and head circumference) were collected monthly using standardized procedures. The weight-for-age (WAZ), length-for-age (LAZ), and weight-for-length (WLZ) z scores were calculated using the World Health Organization (WHO) Growth Standards.

Iron Biomarkers

Blood samples were collected at 7, 15, and 24 months of age and sent to Johns Hopkins University Bloomberg School of Public Health (Baltimore, Maryland) for analysis. Hemoglobin (Hb) was assessed via HemoCue at the time of blood collection to detect anemia (HemoCue, Mission Viejo, CA). Because of the high altitude of the Bhaktapur, Nepal field site (1,401 m), hemoglobin was adjusted by applying a correction factor of -0.3 g/dL (WHO, 2011c). Anemia was defined as Hb < 11 g/dL after adjustment. Ferritin (Ft) and plasma transferrin receptor (TfR) were measured to assess iron status viaenzyme-linked immunosorbent assays (ELISAs) (Ramco Laboratories, Stafford, TX). Because ferritin is an acute phase protein, α-1-acid glycoprotein (AGP) in blood was measured to detect inflammation. AGP levels were assessed using a radial immunodiffustion test (Kent Laboratories, Bellingham, WA, USA). In this study, there was indication that transferrin receptor values were also influenced by inflammation and therefore, both ferritin and plasma transferrin receptor values were adjusted for AGP when AGP>100 mg/L. Additionally, body iron was calculated using ferritin and transferrin receptor values with the following formula proposed by Cook (2003). Negative readings of body iron indicate iron deficiency and positive readings indicate iron sufficiency:

$$Body\ iron\left(\frac{mg}{kg}\right) = -\frac{\left[log10\left(soluble\ transferrin\ receptor\ \left[\frac{mg}{L}\right] x\ \frac{1000}{ferritin}\left[\frac{\mu g}{L}\right]\right) - 2.8229\right]}{0.1207}$$

Dietary Intake

Dietary intake was assessed through periodic quantitative and qualitative assessments of the food consumed during the first two years of life. For the first 8 months, information was gathered about the extent and duration of exclusive breastfeeding and about the introduction of weaning foods collected during the twice weekly and monthly home visits. When a child reached 9 months of age, the caregiver was asked monthly (until 24 months of age was reached) to recall food intake over the past 24 hours (see Appendix 2).

SES and Food Insecurity

Socioeconomic status was assessed at ages 6, 12, 18, and 24 months gathering information on household assets, income, sanitation, and years of maternal education. An aggregate "WAMI" (water, assets, maternal education, and income) score was calculated, ranging from 0-1, with 1 being highest socioeconomic status and 0 being lowest (Psaki et al., 2014). Food insecurity was assessed using the Food and Nutrition Technical Assistance Project (FANTA) Household Food Insecurity Access Scale (HFIAS). This 9-question survey, administered to the mother, primary caregiver, or head of household for each child, inquires about respondents' perceptions and responses to food insecurity. These survey questions can be found in Appendix 1. The HFIAS is scored and respondents are placed into one of four categories – a score of 1=food secure, 2=mildly food insecure, 3=moderately food insecure, and 4=severely food insecure.

Ethics

Appropriate approvals were obtained at all governmental, local institutional, and collaborating institutional ethical review boards. Written informed consent was obtained from the guardian of each participating child.

Statistical Analyses

Prior to analysis, one abnormally high ferritin measurement (Ft = 864 μg/L) at 15 months was deemed an extreme outlier and removed from the data set. There were no other extreme outliers in the data set; however, blood data at 24 months was only reported for 115 participants (as opposed to 236 in the 6 and 12 month data), which is a limitation to the analysis of the data at this time point. Additionally, the distribution of HFIAS categories was highly uneven, so independent t-tests and chi-square tests were used to evaluate whether or not iron status and other health measures differed by HFIAS category. HFIAS data was first calculated as a categorical score (1-4), but participants were only placed into two groups – food secure or food insecure. A score of 1 classified the household as food secure, while a score of 2, 3, or 4 was labeled food insecure. This assignment created two slightly more even groups.

Data was analyzed using SAS 9.4 statistical software. The prevalence of stunting, wasting, and household food insecurity was assessed at 6, 12, and 24 months, while the prevalence of anemia, low ferritin, and high transferrin receptor was assessed at 7, 15, and 24 months.

Chi-square analyses were used to identify the associations between household food insecurity and the following: iron deficiency, anemia, stunting, wasting, gender, and WAMI score. These analyses were performed using data at 6 months (7 months for blood measures) and using data that was averaged from 15-24 months. The relationship between HFIAS and WAMI was analyzed using an independent t-test, as the WAMI score is a continuous variable without defined cutoffs. This analysis was conducted using data averaged from 18-24 months, as WAMI was only collected every six months. P values of less than 0.05 were considered statistically significant.

To assess the contribution of iron deficiency to anemia, chi-square tests were used to evaluate the relationship between anemia and low ferritin and between anemia and high transferrin receptor using data averaged from the 7, 15, and 24-month collections. P values of less than 0.05 were considered significant.

Nutrient adequacy was defined as meeting daily recommended intakes (DRI) (National Academy of Sciences, 2002) of the following selected macro- and micronutrients: protein, protein from meat, fish, and poultry (MFP), animal protein, carbohydrates, fat, iron, iron from MFP, calcium, potassium, zinc, vitamin A, folate, vitamin B6, and vitamin B12. Energy (kilocalories per day) was also assessed. The nutrients in breastmilk were not captured in the dietary assessment. Because more than half of children were still breastfeeding by age 24 months, only the 15-24-month data were used to assess nutrient adequacy, as mean breastfeeding frequency decreased with age. While inability to calculate the nutrients consumed during breastfeeding poses a limitation, low contents of vitamin D, iron, zinc, calcium, and vitamin B6 in breastmilk (Dewey, 2001) at this age will not likely affect the child's classification of achieving adequacy of these micronutrients. However, an adjusted energy value was calculated, as the energy from breastmilk could make a significant difference in total energy consumption. From 12-23 months, the World Health Organization estimates that mean energy intake from breastmilk is 313 kcal/day, assuming a mean milk volume of 448mL/day (Dewey, 2001; Brown et al., 1998). Therefore, 313 kcal/day was then added to total energy consumed (kcal/day) to get an adjusted energy consumption value (adjusted kcal/day). Independent t-tests were used to evaluate the relationship between HFIAS and the intake of each nutrient, including energy. P values of less than 0.05 were considered significant, after applying Satterthwaite corrections for unequal variances.

Results

Table 10 illustrates data revealing stunting rates increased as the children in this study aged, rising from 6.4% at 6 months to 22.9% at 24 months. Anemia decreased as the children aged, falling from 78.6% at 7 months to 38.8% at 24 months. Iron deficiency peaked at 15 months and fell by 24 months, but still affected between 40.9% and 48.8% of children at 24 months, as assessed by Ft and TfR, respectively. Reported food insecurity as captured by HFIAS was low and fell from 6 months to 24 months, from 15.2% to 12.7%, respectively.

Table 10: Prevalence of Stunting, Wasting, Food Insecurity, Anemia and Iron Deficiency

Characteristic	n/N (%)	Mean (s.d.)
Stunting (z<-2)		
6 months	15/236 (6.4%)	
12 months	24/230 (10.4%)	
24 months	52/227 (22.9%)	
Wasting (z<-2)		
6 months	5/236 (2.1%)	
12 months	11/230 (4.8%)	
24 months	7/227 (3.1%)	
Anemia (Hb<11 g/dL)		
7 months	180/229 (78.6%)	10.15 (1.06)
15 months	139/226 (61.5%)	10.60 (1.25)
24 months	45/116 (38.8%)	11.1 (0.99)
Low Ferritin (Ft<12 μg/L)		
7 months	71/213 (33.3%)	25.22 (24.05)
15 months	114/210 (54.2%)	18.37 (60.12)
24 months	47/115 (40.9%)	17.97 (14.32)
High Transferrin Receptor (TfR>8.3 mg/L)		
7 months	145/219 (66.2%)	10.09 (4.76)
15 months	122/223 (54.7%)	9.57 (4.45)
24 months	55/115 (48.8%)	8.88 (4.48)
Food Insecurity (HFIAS>1)		
6 months	36/236 (15.2%)	
12 months	32/231 (13.9%)	
24 months	29/229 (12.7%)	

Tables 11, 12, and 13 reveal no significant associations between food insecurity (as measured by HFIAS) and iron status (as measured by ferritin, transferrin receptor, calculated body iron, and hemoglobin). There was also no significant association between HFIAS and wasting or between HFIAS and stunting at 6 months. There was a significant association between HFIAS and stunting, however, from 15-24 months (p=0.03). Independent t-tests also revealed a significant association between HFIAS and WAMI at both 6 months and the 18-24 month period (p<0.0001).

Table 11: Household Food Insecurity and Child Health Characteristics, 6 months

Characteristic	n/N (%)	Food Secure, % (HFIAS = 1) n=200	Food Insecure, % (HFIAS > 1) n=36	p value
Female	109/236 (46%)	88 (44%)	21 (58%)	0.11
Stunting	16/236 (6.8%)	12 (6%)	4 (11%)	0.26
Wasting	5/236 (2.1%)	4 (2%)	1 (3%)	0.77
Iron Deficiency				
High TfR (TfR > 8.3 mg/L)	143/217 (66%)	122 (66%)	21 (63%)	0.67
Low Ft (Ft < 12.0 μg/L)	70/211 (33%)	62 (35%)	8 (25%)	0.29
Body Iron (ID = BI<0 mg/kg)	87/211 (41%)	77 (43%)	10 (31%)	0.21
Anemia (Hb < 11.0 g/dL)	187/236 (79%)	158 (79%)	29 (81%)	0.83

Table 12: Household Food Insecurity and WAMI, 6 months

	Food Secure (HFIAS=1)	Food Insecure (HFIAS<1)	p value
WAMI score, mean (CI)	0.72 (0.13)	0.60 (0.12)	<0.0001

Table 13: Household Food Insecurity and Child Health Characteristics, 15-24 months

Characteristic	n/N (%)	Food Secure, % (HFIAS = 1) n=187	Food Insecure, % (HFIAS > 1) n=42	p value
Female	107/229 (47%)	86 (46%)	21 (50%)	0.64
Stunting	47/229 (21%)	33 (18%)	14 (33%)	0.03
Wasting	3/229 (1.3%)	2 (1.1%)	1 (2.4%)	0.50
Iron Deficiency (ID)				
High TfR (TfR > 8.3 mg/L)	120/224 (54%)	97 (53%)	21 (53%)	0.93
Low Ft (Ft < 12.0 μg/L)	103/216 (48%)	83 (47%)	19 (50%)	0.75
Body Iron (ID = BI<0 mg/kg)	114/216 (53%)	92 (52%)	21 (55%)	0.74
Anemia (Hb < 11.0 g/dL)	127/226 (57%)	101 (55%)	24 (59%)	0.70

Table 14: Household Food Insecurity and WAMI, 18-24 months

	Food Secure (HFIAS=1)	Food Insecure (HFIAS<1)	p value
WAMI Score, mean (CI)	0.73 (0.71-0.74)	0.60 (0.57-0.63)	<0.0001

Averaging over all time points, 46% of anemic children had low ferritin and 67% had high transferrin receptor. The relationship between anemia and ferritin was more significant (p<0.0001) than between anemia and transferrin receptor (p=0.02).

Table 15: Relationship between Anemia and Iron Deficiency, 0-24 months

	Anemic (Hb<11g/dL), % (n=163)	No anemia (Hb>11g/dL), % (n=68)	p value
Low ferritin (Ft<12.0 μg/L)	75 (46%)	6 (9%)	<0.0001
High transferrin receptor (TfR>8.3 mg/L)	109 (67%)	34 (50%)	0.02

Protein was the only nutrient with a mean intake that met the DRI. Every other nutrient fell short of the DRI. Subjects showed a mean intake of just 26% of the DRI for iron, with 99% consuming <75% of the DRI. Potassium, calcium, vitamin A, and folate also had mean intakes of <50% of the DRI. When adjusted for the additional energy provided by breastmilk, energy consumption still fell short of the DRI (995 kcal), with almost a third of children receiving <75% of the DRI for energy intake.

Table 16: Nutrient Adequacy, 15-24 months

	Mean (95% CI)	DRI	Mean Intake, % DRI	% consuming <75% DRI n=231	Mean Intake Food Secure (HFIAS=1) n=187	Mean Intake Food Insecure (HFIAS>1) n=42	p value, Satterthwaite correction
Energy (kcal/d)	514 (489-534)	995	52%	90% (n=209)	529	465	0.05
Adj. Energy (kcal/d)	827 (802-853)	995	83%	35% (n=81)	842	778	0.05
Protein (g/d)	14.4 (13.6-15.2)	13	111%	22% (n=81)	14.8	12.9	0.07
MFP	1.71 (1.49-1.93)				1.70	1.81	0.78
Animal Protein	6.87 (6.31-7.43)				7.04	6.28	0.34
Carbohydrates (g/d)	77.1 (73.3-81.0)	130	59%	83% (n=191)	78.9	71.4	0.14
Fat (g/d)	16.7 (15.7-17.7)	-	-	-	17.3	14.3	0.01
Iron (mg/d)	1.85 (1.74-1.97)	7	26%	99% (n=229)	1.93	1.56	0.005
Iron from MFP (mg/d)	0.12 (0.11-0.14)	-		-	0.12	0.12	0.98
Calcium (mg/d)	187 (171-202)	500	37.4%	93% (n=214)	194	158	0.04
Potassium (mg/d)	517 (487-547)	3000	17%	100% (n=231)	537	446	0.006
Zinc (mg/d)	1.78 (1.72-1.83)	3	59%	78% (n=181)	1.82	1.56	0.04
Vitamin A (μ/d)	118 (109-127)	300	39%	91% (n=209)	123	101	0.04
Folate (μ/d)	57.8 (54.2-61.5)	150	39%	97% (n=223)	60.8	45.6	0.0002
Vitamin B6 (mg/d)	0.31 (0.29-0.33)	0.5	62%	76% (n=175)	0.80	0.64	0.05
Vitamin B12 (μ/d)	0.77 (0.69-0.85)	0.9	86%	54% (n=124)	0.32	0.29	0.06
Breastfeeding Frequency	8.58 (8.26-8.90)	-	-	-	8.4	9.3	0.02

There were statistically significant differences between the mean intakes of food secure households versus food insecure households for every nutrient except protein, carbohydrates, and vitamin B12. Food secure households consumed more fat (p=0.1), iron (p=0.005), calcium (p=0.04), potassium

(p=0.006), zinc (p=0.04), vitamin A (p=0.04), folate (p=0.0002), and vitamin B6 (p=0.05) than food insecure households. Additionally, food secure households consumed more calories (before and after adjustment) than food insecure families (p=0.05) despite breastfeeding less frequently than food insecure households (p=0.02).

Discussion

The primary finding that HFIAS score did not correlate with iron deficiency is consistent with that of the recent literature. There are multiple possibilities for why household food insecurity and iron deficiency were not significantly related in this study and others.

First, it is important to distinguish that the scale used to determine level of household food insecurity – the Household Food Insecurity and Access Scale (HFIAS) – is a proxy measure. It is entirely possible that household food insecurity does correlate with iron deficiency, but that HFIAS does not accurately capture household food insecurity. Primarily, HFIAS measures perceptions of food insecurity by asking mothers and/or heads of households whether they have perceived certain experiences associated with food insecurity. For example, the first question asks, “In the past four weeks, did you worry that your household would not have enough food?” If the participant responds affirmatively, they are asked to indicate how often (rarely, sometimes, or often). This question targets participants’ perceived anxiety associated with food insecurity but does not target objective measures of food insecurity. A potential problem associated with this type of question is that the respondent may not properly appraise food insecurity as defined by the FAO. For example, if this question were posed to a member of a homogenous community where both their family and the families around them all ate small, infrequent meals with little dietary diversity, they might report much less anxiety over food access than a family whose neighbors were more well-off and better fed, comparatively. This can be said for the majority of the questions in this perceptions-based survey (Appendix 1). Thus, it is plausible that participants in this study underreported food insecurity because their circumstances match the circumstances of those around them. Our findings of significant differences in intakes for most nutrients between the food secure and food insecure households support this hypothesis.

Another potential problem with the HFIAS that could blur the relationship between food insecurity and iron deficiency is the questionnaire's disregard for both economic access to food as well as dietary diversity and nutrition. Again, the definition of food security is "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." While there is no food insecurity indicator that comprehensively addresses all of these components, it begs the question whether or not they have the power to classify participants as food secure vs. food insecure. These indicators, including the HFIAS, are only targeting components of food insecurity. In the HFIAS, for example, 0 questions targeted the components of "economic access" or "safe" and "nutritious food to meet dietary needs and support an active and healthy life". Additional objective questions regarding economic access to food and nutritional quality of food could be added to strengthen the HFIAS.

The lack of nutrition-specific questions is particularly problematic because participants may not understand what proper nutrition looks like and the importance of eating a well-balanced diet. Thus, they may appraise food insecurity differently than households who are schooled on the importance of nutrition. For many around the world, "having enough to eat" just means consuming enough calories to keep you full, and it is unlikely that, without the proper education, families consuming traditional diets with little diversity would consider themselves to be food insecure. For example, if a family is consuming little iron-rich foods and a lot of iron-inhibiting foods (rice, wheat, tea, etc.), but is consuming enough calories to not feel hungry, they can be misclassified as food secure using the HFIAS indicator.

In this study, HFIAS did correlate with stunting, which one might expect. Stunting, defined as a length-for-age z-score of ≤ 2, is an indicator of chronic malnutrition, and food insecurity experienced over a long period of time can lead to chronic malnutrition that manifests as stunting. Although the stunting rate in this study did not match the stunting rates presented in the pre-MAL-ED census data (42% in children from 24-60 months), the rate of stunting was increasing as the children aged. Stunting at 6 months was present in 16 out of 236 children (7%), but stunting from 15 to 24 months was present in 47 out of 229 children (21%). This indicates that the data present in this study would likely match the census data if collected among children of the same age. Moreover, it cannot be argued that this population of children is genetically smaller, as WHO-commissioned research involving 8000 children from Brazil, Ghana, India, Norway, Oman, and the United States of America found that all children everywhere can develop and grow within the same range when provided an optimal growth environment (WHO, 2012). This optimal environment includes following recommended infant feeding practices, having a mother who doesn't smoke, and having access to good health care, etc. This comprehensive study of child growth across the world renders it highly unlikely that children in Bhaktapur are just naturally smaller. If an optimal growth environment is not provided, high rates of stunting can be attributed more to the absence of an optimal environment than to genetics.

Anemia significantly correlated with iron deficiency as assessed by ferritin ($p<0.0001$) and transferrin receptor ($p=0.02$) in this study. Of anemic children, about 46% had low ferritin and 67% had high transferrin receptor. These findings suggest that other nutritional deficiencies besides iron contribute to the development of anemia in this population. This may include vitamin A deficiency and/or folate deficiency, as 91% of children were consuming <75% of the DRI for vitamin A and 97% of children were consuming <75% of the DRI for folate. Further research should work towards identifying the specific causes of anemia in this population to best target appropriate interventions.

Although HFIAS did not correlate with iron deficiency, 15-24 month old children from food secure (HFIAS>1) households did have greater iron consumption than their food insecure counterparts ($p=0.005$). This same trend was seen for most of the nutrients studied. However, while the food secure households had higher overall macro- and micronutrient intake, the mean intakes of this group were still lower than the DRIs for each nutrient. Despite being classified as food secure and consuming more nutrients than the food insecure group, this group still had low overall nutrient adequacy. This again indicates that food insecurity was likely greater in this population than the HFIAS identified, as food secure families on average were still not achieving nutrient adequacy. This was especially apparent in the very low intake of iron in the food secure group, with a mean intake of 1.85 g/d compared to the DRI of 7 g/d. While the food insecure group consumed even less (1.56 g/d), a mean intake of 1.85 is still only 26% of the DRI.

Limitations

A major limitation of this study is the highly uneven food secure and food insecure groups. Had the groups been more balanced in number, more sophisticated statistical regressions could have been used to examine the associations between HFIAS score and iron deficiency and other health indicators, but this was not a viable option for analysis in this study. Additionally, balanced groups would have made for more reliable results on the reported differences between food secure and food insecure households, and the sample size of the "food insecure" population in this study (n=42) was not ideal.

Half of the 24 month blood data was not reported, which likely affected the rates of iron deficiency and anemia reported at that time, given the small sample size (n=115). Additionally, it may have been helpful at all time points to have collected another indicator of inflammation, such as CRP, to help to identify which ferritin and transferrin receptor readings were truly indicative of iron deficiency. The money was simply unavailable for the collection and analysis of an additional blood measure.

Because the contribution of breastfeeding to dietary intake was not captured, the intake values reported were only true for the children who had ceased breastfeeding, which was less than half of children at 24 months. However, we believe that complementary foods contributed significantly more to nutrient intake than what was supplied by breastmilk at the later ages and that values would not have varied greatly if the nutritional profile of breastmilk had been captured. Energy consumption would have been the most affected, thus energy intake was adjusted in this study using reported estimates to correct for this limitation.

Conclusions

Household food insecurity and iron deficiency are two major public health problems in Nepal, but they were not related in this study. Possible explanations lie in the limitations of the Household Food Insecurity Access Scale (HFIAS) in capturing household food insecurity, provided the poor nutrient adequacy yet low food insecurity reported in this population, as well as the lack of questions in the HFIAS targeting important nutritional components of food security. Very low intake of essential nutrients coupled with high rates of iron deficiency, anemia, and stunting suggests that this population has greater food insecurity than the HFIAS identified. Further research should examine the validity of the HFIAS in this context, and measures should be taken to address the low intake of essential nutrients in this population.

Appendix A

HFIAS Survey Questions

Each question is asked with a recall period of four weeks (30 days). The respondent is then asked a frequency of occurrence to determine whether the condition happened rarely (once or twice) sometimes (three to ten times) or often (more than ten times) in the past four weeks.

1. in the past four weeks, did you worry that your household would not have enough food?

2. In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?

3. In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?

4. In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?

5. In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?

6. In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?

7. In the past four weeks, was there ever no food of any kind in your household because of lack of resources to get food?

8. In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?

10. In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?

Appendix B

24-Hour Food Recall Protocol

The day chosen for completion of this food recall interview should not follow a traditional festival, holiday, or celebration at which a non-typical feeding schedule and/or food choices may have been a factor in what the child ate on that day. The purpose of this instrument is to document the child's diet for a typical day. Breast milk feedings will be recorded, but there is no way to quantify this information to obtain nutrient intakes from breast milk. Thus, this protocol obtains quantitative information on intakes of non-breast milk foods, and not total dietary intake. There is a separate Recipe Form for capturing recipes and ingredients. When a recipe cannot be obtained from the respondent, local residents can be consulted to create a composite recipe/nutrient composition. The amounts of each food/recipe consumed by the child within the past 24 hours (as reported by the mother/caregiver) will be used to calculate daily nutrient intakes.

1. Get a complete list of all the foods eaten by asking questions to help the mother/caregiver reconstruct her/his day and that of the child with respect to a) time, b) her/his and the child's activities, and c) food/meal combinations. Example questions include:

- When did (child's name) wake up yesterday morning? What did they have to eat? Did they eat or drink anything after that?
- What did you do after that? At what time was this? Did (name) eat or drink anything before or after that?
- When you went to the market, did (name) go with you? Did you buy anything and feed it to him/her while you were out? If (name) did not go with you, did you leave food with someone else to feed them while you were gone?
- Did s/he take a nap? Did s/he eat or drink anything (or nurse) just before the nap? How about after?
- After you went to bed last night, did you nurse (name) during the night? How many times? Did he or she eat or drink anything else during the night?
- When you fed (name) porridge, did you add anything to it?
- Did (name) have anything to drink with this?
- From the soup, what pieces did you give the child to eat? What else did (name) have at this meal?
- Was the bread eaten plain or did you put something on it? Did you give them more (a second helping)?

2. Go back over the list to get additional descriptions and amounts of the food. Also determine if all of the food was eaten or if some was left on the plate/dish.

- Encourage the mother/caregiver to describe foods as clearly as possible. Use the recipe form to gather information on combination dishes (soups, stews, etc.)

- Get details about the specific portions of food that the child may have been fed (only the broth, a potato and mashed up carrot only, etc.) If bought ask to see package or record the brand name and other pertinent information.
- Use the site specific tool kit to more accurately estimate the amount served/consumed. Have the mother/caregiver show how much by pouring raw rice or dry beans, for example, on a plate or by identifying some item in the tool kit that is of similar size.
- When appropriate ask the mother/caregiver to show the serving container and ask how much of it the child ate (2 pieces, a little bit, ½, ¾, all?). Determine the amount it holds by using rice and a standard measuring cup.

3. After completing the list, read it back to him/her and ask her/him if there is anything else that she/he may have forgotten. Ask about commonly forgotten foods (in that setting).

4. Thank her/him for her/his cooperation. Do not comment on the information.

Guidelines to developing site specific tool kit

- Cups – plastic measuring cups (locally purchased equivalent)
- Bowls – locally purchased of different shapes – holding 1-2 cups
- Small bowl/dish – about ½ cup
- Standard measuring spoons – 1 tablespoon, 1 teaspoon, ½ teaspoon (local equivalents)
- Food models/pictures of common foods served/eaten, or picture-based guide if available
- Plastic container of 1 to 2 cups of rice (with tight-fitting lid). Rice can be used as an example of more dense foods
- Plastic container of 1 to 2 cups of dried beans (with tight-fitting lid). Beans can be used as an example of foods that are more loosely packed
- Plastic ruler – 6" works as well
- 10 shapes on cardboard or plastic – 1" square, 2" square, 3" square, a slice of pizza (or other dish as appropriate to local context), 2 cm slice (cake, quiche, bread, local equivalent), 4" circle (pancake, bread, local example), additional shapes such as circles for portion sizes (local examples) or for various shapes of meat and fish, as locally relevant

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Academic Vita

EDUCATION

The Pennsylvania State University | Schreyer Honors College
B. S. in Biobehavioral Health, Honors in Nutrition | May 2016
International Agriculture, Global Health, and Biology Minors
Honors Undergraduate Thesis: "Food Insecurity and Iron Deficiency in a Cohort of Nepali Children"

HEALTH RESEARCH EXPERIENCE

The Grocery Store Project Summer 2015
Principal Investigator

- Developed and created a personal research project addressing the effects that health marketing claims have on low-income parents' food purchasing choices
- Wrote a grant proposal and received a $3,500 research grant from Penn State University
- Developed, got approved, and made modifications to IRB protocol
- Created recruitment materials & recruited low-income parents at local daycare centers and preschools
- Conducted phone surveys and grocery store visits for 15 study participants
- Prepared nutrition education materials for study participant

The Weed Ecology Laboratory Summer 2015
Climate Change and Food Security Research Intern

- Constructed "rain out shelters" to induce drought stress on test corn plots
- Studied drought stress in test corn plants through a variety of qualitative and quantitative measures
- Read and discussed relevant scientific literature with the research team

2015 Norman Borlaug Dialogue Conference October 2015

- Served as a student representative for Penn State & International Agriculture and Development Program
- Attended a 3-day conference and breakout sessions about global hunger and food insecurity
- Gave findings presentations to 2 undergraduate classes at Penn State

HEALTH COMMUNICATION EXPERIENCE

Penn State HealthWorks Peer Educator 2014 - Present
Physical Activity Team Leader

- Led nutrition workshops for Penn State students
- Created and distributed a cookbook of affordable, healthy recipes for Penn State students living off-campus
- Wrote a column for local newspaper, The Daily Collegian, of WHO guidelines for red & processed meat
- Wrote healthy eating blog posts for college students for Healthy Penn State blog
- Planned and organized a campus-wide Penn State Spring Fitness Challenge

The Healthy Bodies Project Spring 2013 – Spring 2015

Parent/Caregiver Education Team Leader

- Developed a nutrition curriculum & classroom materials for 53 preschool teachers across rural central PA
- Planned & directed a teacher training where 100 teachers were trained on a preschool nutrition curriculum
- Collated classroom data and provided feedback to preschool teachers for monitoring & evaluation purposes
- Planned project's parent/caregiver education team tasks and ran team meetings
- Created audiovisual presentations to disseminate nutrition information to low-literacy parents/caregivers

Young Scholars of Central Pennsylvania After School Program Fall 2014

"Healthy Eating, Healthy Living" K-5th Teacher

- Taught a weekly extended day "Healthy Eating, Healthy Living" program at a local elementary school
- Planned elementary school nutrition and physical activity lessons related to USDA MyPlate guidelines
- Created weekly newsletters for parents of students in the program including healthy recipes to make at home

Summer Nutrition Educator, YMCA and KinderCare Summer 2014

- Developed a nutrition curriculum for preschool & elementary students based on USDA MyPlate guidelines
- Prepared all in-class materials and developed healthy recipes each week
- Taught a class of 30 kids 3 times a week about MyPlate and MyPlate food groups
- Prepared healthy meals with students each week and sent recipes home to parents

Narrator of Penn State's Student Alcohol Feedback and Education (SAFE) Module Fall 2015

- Narrator for a student alcohol safety module that all freshman at all Penn State campuses must complete
- Provided feedback and edited the module's script to make it more college-student friendly
- Starred in 4 videos providing important information on alcohol safety to freshman students
- Audio-recorded the rest of the module's script

Teaching Assistant, Neurobiology 470 Spring 2016

- Held weekly office hours to tutor 70 students needing help in this upper-level neuroscience course
- Graded class exams and assignments

VOLUNTEER EXPERIENCE

Community Food Security Club, President 2014 - Present

- Volunteered, fundraised, and held food drives for local food bank in Philipsburg, PA
- Created healthy recipe packets for Philipsburg Food Bank patrons using foods from the food bank
- Organized a local farmer's market voucher program to provide subsidized produce to low-income families
- Organized a "Hunger Banquet" for 70 people benefitting the food bank voucher program in Philipsburg
- Planned and organized campus documentary screenings to raise awareness of food insecurity in America
- Raised >$2000 for the building of a borehole in a Malawian community in a water crisis

Centre County Food Systems Summit Fall 2015 - Present

Planning Committee/Discussion Facilitator

- Planned the First Annual Centre County Food Systems Summit attended by 80 local community stakeholders, including farmers, educators, government workers, nonprofit workers, and business owners
- Helped to prepare meal using entirely locally-sourced ingredients for all 80 attendees

- Facilitated breakout discussion about community food and nutrition security among 25 attendees

Penn State Student Farm Initiative 2014 - Present
Advocacy and Outreach Project Leader
- Organized meetings with university administrators to develop plans for a student-centered farm on campus
- Served as liaison among other sustainability organizations to galvanize support for a student farm
- Hosted on-campus educational events about local food system

INTERNATIONAL HEALTH EXPERIENCE

Global Health Minor Fieldwork Experience Summer 2015
Dar es Salaam, Tanzania
- Shadowed health care providers in the Buguruni Maternal & Child Health/HIV clinic
- Created an anemia prevention brochure for mothers attending the Maternal and Child Health clinic
- Conducted community health assessments with Muhimbili University nursing students in rural village
- Presented broad assessment findings in a community meeting & encouraged members to develop solutions
- Shadowed at Muhimbili National Hospital in pediatric burn/oncology wards & the emergency department

Penn State Global Medical Brigades Summer 2013
Darién, Panama
- Assisted physicians and dentists during patient visits in rural pop-up medical clinic
- Took patients vitals and entered patient information into a database
- Built latrines in a separate indigenous community to combat water-borne illnesses endemic there

Malini Foundation Social Entrepreneurship & Cultural Immersion Fellow Summer 2014
Sri Lanka
- Taught English and nutrition to Sri Lankan elementary students in a rural village school and orphanage
- Learned about health and education issues among Sri Lankan tea farmers and factory workers
- Learned about nonprofit work, specifically regarding women's rights, in Sri Lanka
- Wrote blog posts for the Malini Foundation's website about my experience in-country

SCHOLARSHIPS AND AWARDS

Schreyer Honors College Academic Excellence Scholarship 2012-2015
Erickson Undergraduate Summer Discovery Research Grant 2015
Francis A. and Ruth C. Wodock Scholarship 2015
Thomas A. Fulton Scholarship 2015
Phi Kappa Phi Study Abroad Grant 2015
World Food Prize Undergraduate Scholarship 2015
Fulbright Research Grant Semi-Finalist, Nepal 2016
Health and Human Development Alumni Society Poster Competition, 1st Place, 2016

SKILLS

Microsoft Word, PowerPoint, Excel, and Publisher
SAS Statistical Software