Food Security Measurement Issues
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Purpose

Identify the major trends and critiques of food security measures within the past five years.

Methodology

Using Scopus, we first pulled 96 academic articles from 2010-2015 that appeared as results from the search string "'food security' AND measurement." We also retrieved 21 articles cited in Jones et al.'s (2011) review of food security measures. In addition, we retrieved 15 articles from 2010-2016 obtained from grey literature sources (e.g., Google, World Bank eLibrary) using the search terms "food security" and "food insecurity."

We coded all the articles for the food security measures the authors use or mention and specified whether the measures: 1) operate at the household or individual level; 2) discuss gender, women or children or other populations (e.g., indigenous populations); and 3) examine willingness to take risks. In addition, we summarized the conclusions of 23 literature reviews providing deeper looks at food security measurement theory and trends.

Theoretical Frameworks of Food Security Measurement

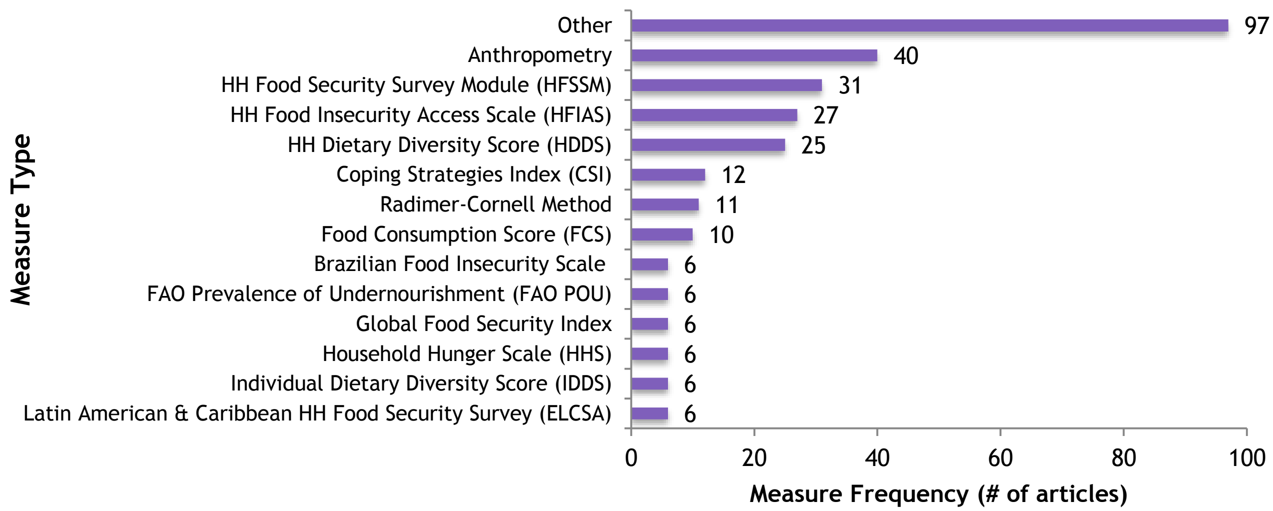
The FAOs's food security pillars – access, availability, utilization and stability – are frequently cited in the literature as organizing principles for food security measurement (Jones et al., 2011; Carletto et al., 2012; Coates, 2013; Ghattas, 2014).

Despite their widespread use, however, many authors note that the "pillars" analogy can hamstring improved food security measurement efforts because each one has not been well-defined (Berry, 2015; Coates, 2013; Moltedo et al., 2014). Some authors recommend new efforts to develop a comprehensive suite of food security indicators that does not adhere strictly to these particular pillars. Coates (2013) proposes one of the more specific sets of indicators that encompass five "dimensions" of food security: (1) food sufficiency, (2) nutrition adequacy, (3) cultural acceptability, (4) safety, and (5) certainty and stability.

Frequently-Cited Food Security Measures

Figure 1 summarizes the frequencies of approaches to measuring food security mentioned in the literature we identified, with individual approaches noted if referenced by six or more articles. Anthropometry (40), Household Food Security Survey Module (HFSSM, 31), Household Food Insecurity Access Scale (HFIAS, 27), and Household Dietary Diversity Score (HDDS, 25), are among the most frequently cited specific measures, although the "other" category was the largest overall (97).

Figure 1. Frequency of Food Security Measures Cited



The large quantity of "other" approaches to measuring food security demonstrates the lack of consensus among researchers about which measurement is the most effective or relevant. Some measures of food security are based on a single indicator, but several are scores or scales derived from a combination of indicators, such as the HFIAS and FSC. Of the measures specifically coded, many are derived from Household Consumption and Expenditure surveys (HCEs), such as the HFSSM and the Latin American & Caribbean Household Food Security Survey (ELCSA).

In addition, some measures and surveys have been developed to estimate food security at a regional level, such as the Brazilian Food Insecurity Scale and ELCSA, to reflect differences in the characteristics of the food insecure in different contexts. The new region-specific food security surveys reflect a growing recognition among researchers that food security is determined by many regional and culturally specific factors, and cannot be adequately measured by one universal survey. Region-specific surveys are modified versions of the more universally applied HCEs and are based on the same theoretical assumptions, differing primarily in food types discussed (Ghattas, 2014).

Ninety-five of the articles reviewed mention measurement at the household level of consumption, while 60 discuss measurement at the individual level of consumption, and some of these articles mention both. Child-specific measures of food security were mentioned in 43 articles (usually anthropometry), and 33 mentioned gender-specific measures (typically disaggregating men and women, but sometimes asking specific questions by gender).

Levels of Measurement

The following categories are the most commonly discussed measurement levels within the recent food security literature.

I. Individual-Level Measurement

Anthropometry is one of the most popular individual-level approaches to measuring food security and is thought to address the FAO's "utilization" pillar. This broad category includes such measures as wasting, stunting, and body mass index (BMI). Anthropometry also incorporates the issue of weight—both underweight and overweight—that is not typically captured in household-level surveys (Segall-Correa et al., 2014). However, Ghattas (2014) reports that results vary depending on the economic status of a given country, with higher rates of double health burdens, such as stunted children also with overweight women, in places with a lower economic status. Coates (2013) and Anema (2014) argue that anthropometry can be problematic because it may conflate outcomes with causes, as anthropometric measures generally reflect nutritional status which is not only determined by food security status, but also by health, hygiene, and access to clean water and services.

Another individual-level approach to measuring food security is through nutritional dietary surveys. However, these are complicated, expensive, and labor-intensive, so it can be challenging to get a large enough sample size to make statistically significant claims (Moltedo et al., 2014; Jones et al., 2013).

II. Household Consumption and Expenditure Surveys (HCEs)

Household surveys yield information about household expenditure decisions and take the actual demographic structure of the household into account (de Haen, 2011). However, HCEs do not take into account seasonal fluctuations in food availability or that food consumed outside of the home (de Haen, 2011). They are also costly to implement and tend to be infrequently administered (Jones et al., 2013; de Haen, 2011). Additionally, they usually only collect food data for a short reference period and inaccurately assume that household food consumption is the same as household food acquisition (de Haen, 2011, Jones et al., 2013).

Other authors critical of HCE-based approaches to food security measurement note that household surveys typically do not include information on the broader structural determinants of food security like social, economic, and agricultural policies (Ghattas, 2014). Furthermore, all households, even low-income ones, produce some amount of food waste that is not accounted for (Moltedo et al., 2014). Experience-based measures are also subject to response bias deriving from unique personal and cultural values, individual responses that may not reflect the opinions of the household, and recall bias of food consumption periods (Jones et al., 2013).

Perhaps most importantly from a measurement perspective, recent research suggests HCE results can vary significantly based on survey design, with some authors arguing HCEs should be only be used with great caution until more consistent and comparable (“harmonized”) survey data collection can be completed (de Weerdt et al., 2015; Carletto et al., 2012).

III. Cross-National Measures

The FAO prevalence of undernourishment (POU) is one of the most common cross-national measures and is published every three years in “The State of Food Insecurity in the World (SOFI)” to inform the global community about levels and trends of undernourishment. This measure was also used to track progress on the first Millennium Development Goal (de Haen, 2011). Based on the notion of an average individual in a reference population, the POU compares usual food consumption, expressed in terms of dietary energy (kilocalories), with calorie requirement norms (Naiken, 2002).

The POU is an oft-critiqued yet still-valuable measurement because calories available per capita—derived from food balance sheets—is comparable cross-nationally and measures are available every year because it is not measured at the individual or household level. However, as a stand-alone measure, it does not capture the complexity of all dimensions of food security (Berry, 2015), though it does help evaluate food supply and shortages (Jones et al., 2013). In addition, national-level measures do not identify equality issues at the sub-national level and may not represent the food security status of minority groups, women, children or others (de Weerdt et al., 2015).

Discussion

The most common observations noted across the literature reviews fall into two categories. First, in multiple literature reviews, food security measures are criticized for not accurately characterizing food security at a particular scale (Barrett, 2010; Coates, 2013; Carletto, 2012). However, such shortcomings may result when a food security measure is applied at an inappropriate level of measurement. Cross-national data based on food balance sheets cannot be disaggregated to evaluate the food security situation of specific populations, for example, whereas data from household surveys may be used to study different populations. The question of what measure to use requires tradeoffs between measures that may be comprehensive and contextually relevant yet burdensome to implement versus measures that are simpler to compute and provide more comparability yet do not capture all the important elements of food security (Jones et al., 2013).

Secondly, several authors discuss how a suite of indicators that apply at different scales is potentially more productive than a single, universal food security measure (Barrett, 2010; Coates, 2013). Coates' (2013) five dimensions of food security (mentioned previously) form a framework that applies at the global/national, household, and individual levels. For the food sufficiency dimension of the framework, for example, Coates identifies existing food security measures like the POU indicator, Household Hunger Index Score, and Individual Hunger Index Score that satisfy the sufficiency dimension at a particular scale (see *Table 1*).

Table 1. Sample measures as they fit into Coates' (2013) five dimensions of food security.

Level of Measurement	Food sufficiency	Nutrient adequacy	Cultural acceptability	Safety	Certainty and stability
National/global	POU indicator				Coefficient of variation of food prices
Household	Household Hunger Index Score	Household Dietary Diversity Index Score			Coping Strategies Index
Individual	Individual Hunger Index Score	Individual Dietary Diversity Score			Individual Food Security Access Scale

Source: Coates, 2013

By comparison, Coates (2013) does not believe that the food safety dimension can be satisfied with existing measures, and suggests developing new ones, along with an overall aggregate measure of all five dimensions to meet broad advocacy needs. The author does not dismiss the value of a broad measure to tell a story and compel action, but still emphasizes the role of focused measures to operationalize action.

Finally, as de Weerdt, et al. (2014), note and as we observed in the course of this literature review, few standards exist for using specific measures, particularly those at the household and individual level like Household Consumption and Expenditure surveys (HCEs). The ability to compare results across populations or even within regions in one country is limited if every researcher measures food security differently. Although ideas for standardizing measurements differ, the need for standardization is observed by multiple authors on this topic (de Weerdt, et al., 2014; Coates, 2013; Carletto, 2012).

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Food Security and Poverty
EPAR Research Brief #319b

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Purpose

Identify relationships and major trends between food security and poverty in the academic and grey literature to understand the current research on these two topics.

Methodology

For this overview, we first used Scopus and Google Scholar to find relevant articles pertaining to the relationship between poverty and food security. For Scopus, we used the search strings (poverty AND “food security”) and (poverty AND “food insecurity”) searching in titles only for the years 2005-2015. This search yielded 103 search results, all of which we reviewed and coded. In addition to Scopus, we searched in Google Scholar for articles with “poverty” and “food (in)security” in the title exclusively (allintitle: "poverty" "food security") and (allintitle: "poverty" "food insecurity"). This search yielded a total of 462 results, of which we coded the top 50 results of both searches. Forty-eight of the 100 Google Scholar search results were duplicates from the Scopus results. We chose these particular search strings because they resulted in the most relevant articles that compared the relationship between food security and poverty. We reviewed a total of 175 academic articles, from which we recorded the citation information and major topics discussed in relationship to food security and/or poverty.

We also used Google to conduct a search of the grey literature to determine if there is other ongoing research or noticeable trends that are not published in the academic literature. For this search, we used the following search strings: (“food security” AND poverty), (“food insecurity” AND poverty), (link between “food security” AND poverty), (impact of poverty on “food security”), (impact of “food security” on poverty), and related search terms.[1] For the (“food security” AND poverty) search, we reviewed the first 100 Google search results. We reviewed the first 50 Google search results for all other search strings because many of the search results were duplicates of the original search results. From these searches, 75 new search results appeared relevant based upon a brief reading and the title and abstract or introduction. Upon further review, 36 search results appeared to have especially useful supplementary information in addition to what surfaced in the academic literature review. In this overview, we review the topics most frequently mentioned in the academic and grey literature on the relationship between food security and poverty.

Definitions

The definitions of food security and poverty are subjects of debate amongst experts. For food security, the World Food Summit of 1996 definition of “when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life” (WHO, 2015) is the most frequently cited. In addition,

[1] Other search combinations included: (“food security” equals poverty), (“food insecurity” causes poverty), and (“food security” AND poverty correlat*)

food security measurement is usually oriented around FAO's food security pillars – access, availability, utilization, and stability. For a deeper discussion on food security measurement, refer to EPAR research brief 319a on Food Security Measurement Issues.

Defining poverty is also complex, and while not the primary subject of this brief, an oft-cited 2003 paper by Laderchi, Saith, & Stewart (2003) discusses four approaches to measuring poverty: the monetary approach (a shortfall in consumption from some poverty line); the capability approach (the basic capabilities to live a "valued" life); social exclusion (a measure of the level of marginalization and deprivation within a society); and the participatory approach (views on poverty by the poor themselves). The idea of absolute and relative poverty is also pertinent to this discussion, where absolute poverty refers to a failure to meet fixed subsistence, health, and basic household needs, and relative poverty adjusts needs relative to the standards of living in a society (Wratten, 1995). Laderchi, Saith, & Stewart (2003) find that the monetary approach is the most frequently used in descriptions and analysis, while Wratten (1995) notes that the World Bank and many governments favor the absolute approach. However, the abstracts in the food security literature we reviewed do not often identify the poverty approach they use. The lack of an agreed-upon definition for both poverty and food security may partially explain the inconsistent findings in the literature.

Of the 175 articles reviewed, 17 discuss how either poverty and/or food security is measured in the title or abstract of the study. Several of these studies discuss "food poverty," "nutrition-based poverty lines," or other means of measuring poverty by including a minimum intake of diet related inputs (calories, nutrition, etc.) (e.g., Ouedraogo et al., 2007; Rhoe et al., 2008; Dixit, 2011). These additional concepts further confound the definitions of poverty and food security.

General Trends in the Academic Literature

Of the 175 academic articles reviewed, just six focus on empirically testing the relationship between food security and poverty. Instead, all 175 discuss food security and/or poverty in relationship to another topic area, such as climate change, obesity, agricultural productivity or technology, and economic development, among other topic areas. Of these articles, sixty-four include the terms "food security" and "poverty" somewhat interchangeably, implying that the two are sometimes used synonymously or as indicators for each other. For example, Enete et al. (no date) do not distinguish between food insecurity and poverty in their study of urban agriculture and urban food insecurity/poverty in Nigeria. Additionally, some authors simply assume a correlation between "food security" and "poverty". Ahmed et al. (2013) explicitly claim as a working assumption that "Poverty is the principal cause of food insecurity" without further substantiating the claim. An additional twenty-seven articles examine a related topic area, such as broiler farming, aquaculture, and ethanol production, and examine the relationship between the chosen topic area and poverty and food security as separate correlates.

Among the six articles that do directly empirically investigate the relationship between food security and poverty as the main topic of the study, we find a lack of consensus regarding the nature of this relationship. Maitra et al. (2015), Chimeddalum et al. (2008), and Short (2002) find a positive correlation between poverty and food insecurity. In contrast, Alcaraz et al. (2008) find that "food insecurity does not always reflect (income) poverty." Similarly, Suryanarayana et al. (2007) find that poverty does not always correlate with food security due to different measurement baselines, observing that "estimates of poverty are made on the basis of measures such as consumer expenditure distributions (at current prices) with reference to a base year monetary norm, which is adjusted only for price changes," yet "estimates for deprivation in physical access to food are made in terms of physical measures (which respond to changes not only in prices, but also tastes and preferences as well as a host of other variables such as levels of living and infrastructural facilities) with reference to a constant base-year physical norm" (103). In line with Suryanarayana et al.'s observation that the relationship between food security and poverty depends on measurement baselines, Wight et al. (2014) look at two different definitions of poverty – the official poverty measure (OPM) and the supplemental poverty measure (SPM) - to examine the differences between the two measurements when analyzing the link between poverty and food insecurity among children. They find that poverty and household food security are statistically significantly associated among children, but the association is stronger using the SPM (all money income and other benefits) than the OPM (financial resources compared to a set of thresholds) (Wight et al., 2014).

General Trends in the Grey Literature

A review of the grey literature reveals trends both consistent and inconsistent with those discovered in the academic literature. The majority of the search results suggest that poverty causes or leads to food insecurity (Grace Communications Foundation, 2010; World Food Programme, 2013; Meade, Valdes, & Stacey, 2004). Similarly, several authors explain that a reduction in poverty is necessary for improving food security (Nielson, 2001; Stamoulis & Zezza, 2002). Two results suggest that food insecurity might cause or increase poverty, but the logic behind these claims was unclear (SESRTCIC, 2006; Sharma, 2012). Poverty and food security are frequently cited as closely related concepts, and several articles state that it will be extremely challenging to address poverty and food security as separate issues (Asian Development Bank, 2012; Amaza, et al., 2009; Weingartner, et al., 2005; Patnaik, 2005).

Twelve of the 37 grey literature search results – including several more recent papers – argue that the food *system*, rather than food production, should be the focus of food security solutions (Tacoli, Bukhari, & Fisher, 2013; European Commission Joint Research Centre, 2015; Sati, 2015). Some documents further discuss how food insecurity is due to failures in economic and political systems that make it difficult for families to escape poverty and achieve food security rather than a lack of overall food production (Martin, 2010; Gonzalez, 2015).

In addition, the grey literature search results suggest that global sentiment has refocused from agricultural intensification to sustainable agriculture in recent years. Several authors suggest that this shift away from agricultural intensification will promote sustainable food security and reduce poverty levels (Raney, Skoet, & Lowder, 2014; Shindelar, 2015). Furthermore, recent studies find that climate change and environmental issues, such as land degradation, are drivers of increased food insecurity and poverty (United Nations University, 2015; Scherr, Wallace, & Buck, 2010; Jayne, 2012).

Lastly, a few search results connected food security and poverty to other related topics, including biofuel production (FAO, 2008), fisheries and aquaculture production (World Fish Center, 2011), and the need to empower women in agriculture (Smith, 2015).

Discussion

Only six academic studies focus on the direct relationship between poverty and food security. These studies present different findings on the nature of this relationship, which may be due to differences in the definitions and modes of measurement of both poverty and food security. For instance, some measurements of poverty, including "food poverty," by definition include food security components while others do not. The lack of a common definition for either poverty or food security among the studies reviewed makes cross-comparisons among these studies challenging.

The differences in the studies we identified indicate that the choice of measures can influence the findings and therefore the policy implications when considering the relationship between poverty and food security. It might be worthwhile to explore the most commonly used definitions of food security and poverty, and to conduct a study that examines the relationship between different chosen definitions of poverty and food security to see how they compare.

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Food Security and GDP
EPAR Research Brief #319c

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Purpose

Summarize relationships and major trends between food security and GDP in academic and grey literature.

Methodology

This review summarizes the most frequently mentioned topics in the existing literature on food security and GDP. We reviewed the first 100 results on Scopus and first 50 results on Google Scholar using the search ("food security" AND "Gross Domestic Product" OR "GDP"). We screened the articles for relevance, and recorded the major topics discussed related to food security. A supplementary Google search revealed an additional three relevant recent reports which were also included in this review.

General Trends in the Literature

Our search of the academic literature yielded 142 results in Scopus and 50,700 in Google Scholar. However, few articles directly link GDP to food security. Many of the search results discussed agricultural growth and climate change or other environmental factors as they relate to GDP or food security, and many did not focus on either GDP or food security. Forty of the 150 articles reviewed referenced GDP in the abstract as a descriptor of a country's economic standing, but did not mention GDP in the title or the rest of the abstract. Twenty out of the 150 articles reviewed simply mentioned food security at the end of the abstract as an important consideration of the article's main topic, along with other topics such as climate change, water management, and urbanization. In addition, several articles used GDP as an indicator or proxy measurement for food security (Wu et al., 2010; Wu et al., 2011; Luan et al., 2013). None of the articles focused on estimating the direct relationship between measures of GDP and food security, just three discussed this relationship.

Three general themes emerged from the Google searches for grey literature. First, discussion of food security and "economic growth" broadly with little reference to "Gross Domestic Product" or "GDP" specifically is a common theme among reports in the grey literature (FAO, 2012; Economist Intelligence Unit, 2014; Torero, 2014), indicating that a broader literature search may yield more relevant studies of the relationship between food security and economic growth. In addition, many results from the Google search were reports that reference a country's agricultural contribution to GDP broadly, but do not discuss the relationship between GDP and food security specifically (USAID, 2015; Economic Research Division, 2010; Badiane, 2011). Lastly, several search results examined the relationship between changes in food consumption patterns and GDP, particularly increased consumption of animal protein as GDP increases, and the broad implications of these changes on food security outcomes (Gerbens-Leenes et al., 2010; Allison, 2011).

Overall, the geographic scope of countries reviewed was expansive, including a diversity of countries from the developed to the developing world.

Relevant Academic Literature

While most of the reviewed academic literature revealed little on the direct relationship between GDP and food security, three articles stood out as relevant sources that draw a relationship between both GDP and food security.

Jha & Mehta (2010) find that hunger has risen as GDP has grown in the Philippines: "'The Social Weather Stations' (SWS) hunger index clearly indicates sharply deteriorating food security beginning in 2003 (Figure 14.1). This has occurred despite the country's longest spell of uninterrupted growth in per capita real gross domestic product (GDP) since the 1980s" (432). The authors suggest this trend may be driven by rising food prices, particularly rice prices, in the poorest parts of the country beginning in 2003.

In contrast to Jha & Mehta's (2010) findings for the Philippines, Verpoorten et al. (2013) report a correlation between GDP growth and reduction of food insecurity in Africa, despite increases in food prices: "We also find that it is highly likely that strong GDP growth over the recent years has improved food security in a large number of SSA countries, compensating a possible negative impact of food price increases even on net food consuming households" (63). Although Verpoorten et al. report a positive correlation between self-reported food security and GDP growth, they do not specify the mechanism underlying this relationship.

Finally, Wiebelt et al. (2013) model the impact that climate change will have on agricultural production, household incomes, and food security in Yemen. Controlling for household age and sex composition, education level, qat consumption, access to water and sanitation, rural or urban location, and agroecological zone, Wiebelt et al. find: "Our simulation results suggest that climate change-induced price increases for food will raise agricultural GDP while decreasing real household incomes and food security," indicating that GDP and food security may move in opposite directions (77).

These three articles were the only academic articles reviewed that examined the direct relationship between food security and GDP. However, the relationship between GDP and food security was not the main topic of any of these papers, which focused on the food price crisis, food aid programs, and the impact of climate change, respectively.

Relevant Grey Literature

In addition to our search for academic literature on Scopus and Google Scholar, we conducted a Google search and found three recent reports that discuss the relationship between GDP and food security.

The Food and Agriculture Organization (FAO)'s (2012) "State of Food Insecurity in the World 2012" report includes a comprehensive study of the relationship between components of food security, including hunger and malnutrition, and economic (GDP per capita) growth and agricultural growth using FAO and World Bank data. The report finds that GDP growth is a necessary but insufficient component for improving food security: "High growth rates of GDP per capita are a key factor in reducing food insecurity and malnutrition. However, economic growth per se does not guarantee success" (p. 4). Quoting Jean Dreze and Amartya Sen, the report states that improvements in food security outcomes require public policies that ensure the benefits of economic growth are shared equitably and are used for social services, particularly public healthcare and education.

The Economist Intelligence Unit (EIU) (2014) claim a positive correlation between GDP and food security. They state that "Gross domestic product (GDP) per capita (at PPP exchange rates) provides insight into the relative wealth of a country and the ability of the average citizen to consume […], countries with higher GDP tend to have higher food security" (p. 18), but do not provide evidence to support this claim. The EIU further examines the empirical relationship between GDP and "food loss," which measures post-harvest and pre-consumer waste and captures inefficiencies in the food supply chain, finding a negative relationship between "food loss" and income level (measured by GDP per capita, adjusted for purchasing power parity). The EIU further emphasize the intersection between "food loss" and food security in a follow-up report, "Global Food Security Index 2014 Special Report: Food Loss and Its Intersection with Food Security," in which they again conclude that post-harvest losses and food waste are negatively correlated with GDP.

In a recent IFPRI blog post, Torero (2014) cites several empirical studies to discuss how food insecurity contributes to economic decline: "High rates of malnutrition can lead to a loss in gross domestic product (GPD)[sic] of as much as 4 to 5 percent, according to the UN Food and Agriculture Organization." Torero further discusses the potential negative consequences of economic growth on nutrition, particularly obesity and other diet-related diseases. In conclusion, Torero argues: "Food security is central to both short- and long-term economic growth and it needs to be a central part in a larger cross-sectoral strategy at the national, regional and global levels."

Unlike the academic literature, the grey literature, particularly following the FAO report, "State of Food Insecurity in the World 2012" frequently discusses direct relationships between food security and economic growth, including GDP. But while the grey literature often suggests that food security outcomes and GDP growth are associated with one another in some capacity, such claims are only rarely supported by empirical evidence.

Discussion

A review of the academic and grey literature to date revealed only limited empirical research into the relationship between food security and GDP. The 2012 FAO report on world food insecurity provides perhaps the most comprehensive discussion of links between food security and GDP, ultimately concluding that food security is associated with but not determined by economic growth (GDP per capita).

Although economic growth may contribute to enhanced food security as Verpoorten et al. (2013) and the EIU (2014a; 2014b) find, additional factors including food price rises (Jha & Mehta, 2010), climate change (Wiebelt et al., 2013), inequality (FAO, 2012), lack of social services (FAO, 2012), and over-nutrition (Torero, 2014) complicate analyses of possible relationships between economic growth and food security and nutrition outcomes in any given country.

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Food Security and Crop Yield
EPAR Research Brief #319d

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Purpose

Identify the relationships and major trends between food security and crop yield in the academic and grey literature.

Methodology

We used Scopus and Google Scholar to identify relevant articles pertaining to the relationship between food security and crop yield. We searched title, abstract, or keyword for sources published from 2005-2015 and pulled the first 50 results for "food security" and the first 50 for "food insecurity" in Scopus, and the first 25 results for "food security" and the first 25 results for "food insecurity" from Google Scholar. We chose dual food security terms because the literature uses both, and because this approach yielded the most relevant results. A total of 150 articles were screened for relevance. A supplementary Google search revealed an additional three relevant and recent studies.

After identifying relevant articles, we reviewed each article for discussion of any of the following relationships between crop yield and food (in)security:

(1) crop yield depends on food (in)security;
(2) food (in)security and crop yield are one and the same;
(3) food (in)security depends on crop yield; and
(4) no relationship exists between food (in)security and crop yield.

In addition, we coded for whether the article discussed climate change, crop yield models (historical or prediction models) and for the methodology used (e.g., field study results, crop yield models, meta-analysis of other empirical studies, or mixed research methods) to link food (in)security and crop yield.

Definitions

Though the definition of food security is debated among experts, the 1996 World Food Summit definition of food security is the most frequently cited: "When all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (WHO, 2015). Food security measurement is often oriented around FAO's food security pillars – access, availability, utilization, and stability. A widely cited study by Butt et al. (2005) refers to the "food security implication" of a population at risk of hunger under climate change models, using the FAO's "Risk of Hunger" methodology to show the percentage of the population that is malnourished in a country or region. To some researchers, "hunger" is a specific measured element of food security, and should not be used interchangeably with food security (National Research Council of the National Academies, 2005). For a further review of issues in food security measurement, refer to the EPAR research brief #319a, *Food Security Measurement Issues*.

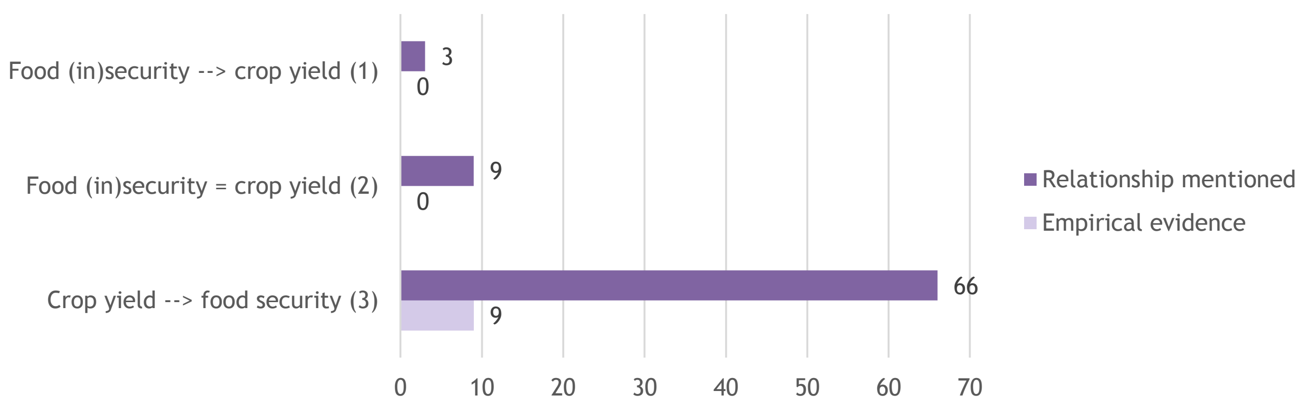
Just as with food security, there are numerous definitions of crop yield. The most common method is the quantity of harvested crop divided by area harvested (Reynolds et al., 2015). However as summarized in EPAR Technical Report #321, *Topics and Challenges in Agricultural Productivity Measurement,* there are many alternative ways of measuring yield including total factor productivity (Rezek, Campbell, & Rogers, 2011), yield by area planted (Fermont & Benson, 2011), production value per area (Aguilar, A., Carranza, E., Goldstein, M., et al., 2015) or technical efficiency (Mekonnen et al., 2015). Some studies use "crop production" or "productivity" interchangeably (Palazzolli, et al., 2015; de Graffenried, 2006; Najafi & Lee, 2014). Ferroni & Zhou (2015) discuss how crop yield itself measures not only the productivity of land, but also the success of agricultural research, plant breeding, and the delivery of research goods to farmers. The existence of more than one crop yield measure raises questions about comparability across studies.

General Trends in the Literature

Few articles focus directly on the relationship between food (in)security and crop yield. Climate change is a frequent focus of study, with 71 articles mentioning this topic. Crop yield models relate closely to climate change issues, and many authors use complex models to review or to forecast crop yields under different climate patterns, temperatures, ozone levels, or irrigation types. In total, 65 articles include a crop yield prediction model of some kind. Other frequently mentioned topics include soil health, nutrition content of crops, biofuels, biodiversity, crop diseases and pests, and water supply.

Of the literature reviewed, three sources argue that crop yield depends on food security (relationship 1), and nine sources use food (in)security and crop yield interchangeably, implying that measures of either can be used as indicators for the other (relationship 2). Relationship 3, that food (in)security is dependent on crop yield, is the most frequently referenced, with 66 articles making this link (*Figure 1)*. No sources supported relationship 4 (that no relationship exists between food (in)security and crop yield), although this may in part reflect a well-established bias in the academic literature against null findings (Rosenthal, 1979). Nine articles offer empirical evidence to substantiate the relationship between food (in)security and crop yield, and all of these supported relationship 3, that food (in)security is dependent on crop yield.

Figure 1. Food (in)security and crop yield frequencies and corresponding empirical evidence



Empirical Evidence from Academic Literature

We did not find any empirical evidence directly testing the association between food security and crop yield. Nine studies, however, offer empirical evidence of the effect of various factors on crop yield, and the authors then discuss expected impacts of these changes in crop yield on food security based on an assumed relationship between the two (relationship 3). Factors impacting crop yields in the nine studies include climate variability, soil health, and farm management (Long & Ainsworth, 2005; Schreinemacher, 2005; Ye & Van Ranst, 2009; Magcale-Macandog et al., 2010; Quinn, Okori, & Gidudu, 2010; Wu et al., 2011; Mainuddin, 2013; Ye et al., 2013; Fuss et al., 2015). Evidence to support these relationships includes meta-analysis (Long & Ainsworth, 2005), a partial equilibrium model (Fuss, 2015), crop yield models (Ye, 2009; Quinn, Okori, & Gidudu, 2010; Wu et al., 2011; Mainuddin, 2013; Ye, 2013), and mixed methods participatory approaches (Schreinemacher, 2005; Magcale-Macandog et al., 2010).

Climate variability is a common theme across this literature and in the empirical evidence, generally in terms of how climate change will affect crop yields, which in turn is argued to affect food (in)security. Quinn, Okori, & Gidudu (2010) show how satellite weather data used to predict crop yield can be clustered at the household level and used as an indicator of food security to inform famine warnings for specific areas and different population groups. Mainuddin (2011) argue that despite climate change conditions in the Mekong Delta, absolute irrigated and rainfed rice yields will likely be sufficient to ensure food security for the area's increasing population, barring an extreme weather event. Long & Ainsworth's meta-analysis (2005), however, suggests that future crop yield gains under climate change conditions (including due to increasing CO_2) are often overstated, which has led to inflated predictions of future food security globally, though they do not demonstrate the relationship between changes in crop yield and food security. Fuss (2015) uses a partial equilibrium model to argue that food security requires overproduction on existing land to meet minimum food supply constraints in the context of global climate change.

In one of the most comprehensive empirical analyses of climate change, yield, and food security relationships to date, Ye et al. (2013) evaluate crop yield estimates under variable climate conditions in China. They model climate and yield change impacts on a "food security index," an index featuring grain self-sufficiency they claim to be relevant for populous Asian countries that are too large to rely on food imports (i.e., China). They compute this measure by dividing *s*, the per capita food supply by *g*, the expected food self-sufficiency level in China (95%) and subtracting *d*, per capita food demand, then dividing this result by *d*, to measure the general status of food security in China (see equation 1).

$$FSI = \frac{s/g - d}{d} \cdot 100 \qquad (1)$$

Using regression analysis that correlates the food security index and crop yield, they find that the yield growth rate is a better indicator of food security than crop yield itself, which is significant for countries with growing populations like China.

Soil degradation and farm management practices also feature as topics in the evidence, again in terms of how they affect crop yields and in turn food security. Ye & Van Ranst (2009) simulate the effects of soil degradation on crop yields and long-term food security in China, and they infer that projected yield losses will not sustain China's growing population under the current management level. Magcale-Macandog et al. (2010) evaluate the role of agroforestry on household food security in the Philippines using participatory approaches to show that agroforestry increased and stabilized some yields and offered secondary food crops during lean months. They use this evidence of increased yields to argue that household food security (measured using a combination of household survey results, focus group discussions, field experiments, bioeconomic modeling, and investment and profitability analysis) increased and that such practices offer a greater level of benefits than monocropped systems. Wu et al. (2011) link a GIS-based spatial model to food security when they estimate potential yields under specific biophysical, social, and economic scenarios using per-capita GDP and food availability as indicators of food security. These two indicators proxy four dimensions of food security (availability, stability, accessibility and affordability, which is linked to utilization) and projects food (in)security across developing and developed countries under various climate, crop yield, and crop price scenarios. To determine food security status, Wu et al., (2011) combine yield with crop sown area data derived from a crop choice decision model to determine total food production, and join that with population growth rates to determine per capita food availability (see Appendix A).

Schreinemacher (2005) tests the hypothesis that food (in)security is dependent on crop yield in India. Using a model including a mathematical interpretation of human decision-making, spatial layers of soil properties, and a crop yield simulation that food security depends on crop yield, the author ultimately concludes that neither the width in the yield gap nor its change over time relate to food security over time in India. However, he does not refute that crop yield relates to food security, merely suggesting that there are other factors, like access to innovations and credit, that are more important.

Discussion

The studies reviewed provide limited evidence that food security is associated with crop yield. In many studies, measures of crop yield are used as indicators of food security, meaning the association between the two is assumed rather than tested, and pointing to issues in the measurement of both food security and crop yield. Most of the evidence focuses on changes in crop yield, and discusses how these changes might be expected to impact food security. For example, Clair & Lynch (2010) review the literature on climate change and soil fertility and discuss the effects of climate change on crop yield and nutritional quality, with soil health as their primary food security indicator. Lal (2009) also reviews the literature and points to evidence that soil degradation is a key indicator for food security through its impacts on crop quality (nutrition) and quantity (yield).

Tension exists between researchers who argue for crop production intensification on existing agricultural land to increase yields and satisfy global food demand (and by extension, to support food security) versus those who warn against the impacts of intensification on long-term soil health and biodiversity (Tscharntke et al., 2012; Chen, et al. 2011; Bommarco, Kleijn, & Potts, 2013; Kang, Khan, & Ma, 2009). Tscharntke et al. (2012) contend that smallholder farming preserves biodiversity and food security, and that intensification on smallholder plots does not necessarily disrupt biodiversity, while commercial intensification does.

The role of innovation and accelerated genetic gains to improve crop yield and global food security is discussed by many authors (Tester & Langridge, 2010; Najafi & Lee, 2014; Ferroni & Zhou, 2015) while others, like Schreinemacher (2005) argue that addressing other issues, like labor productivity and access to credit, is more important. In a blog post drawn from the International Food Security Assessment 2014-2024, Rosen et al. (2014) offer further support for the role of agricultural technology when they show that increasing the percentage of land growing modern plant varieties in Sub-Saharan African improve food security (see Appendix B).

Moges & Holden (2011) find that the majority of Ethiopian smallholder farmers identify declining soil health when they harvest reduced yields but make little conservation effort due to limited resources. Xiaoxuan (2014) observes the global commodification of soil that reflects a near-term focus on crop yield at the expense of long-term soil replenishment and food security. As far as determining the role of humans in climate change-related effects on agriculture, Porter (2014) notes that few studies focus on the anthropogenic influence on changing climatic trends, but anticipates this changing in the next few years as agricultural modeling studies expand to broader scales (2014).

Overall, the biggest challenges facing this analysis relate to how food security and crop yield are measured, discussed, and defined. Future, deeper inquiry into these and other sources could track measurement methods and trends among researchers.

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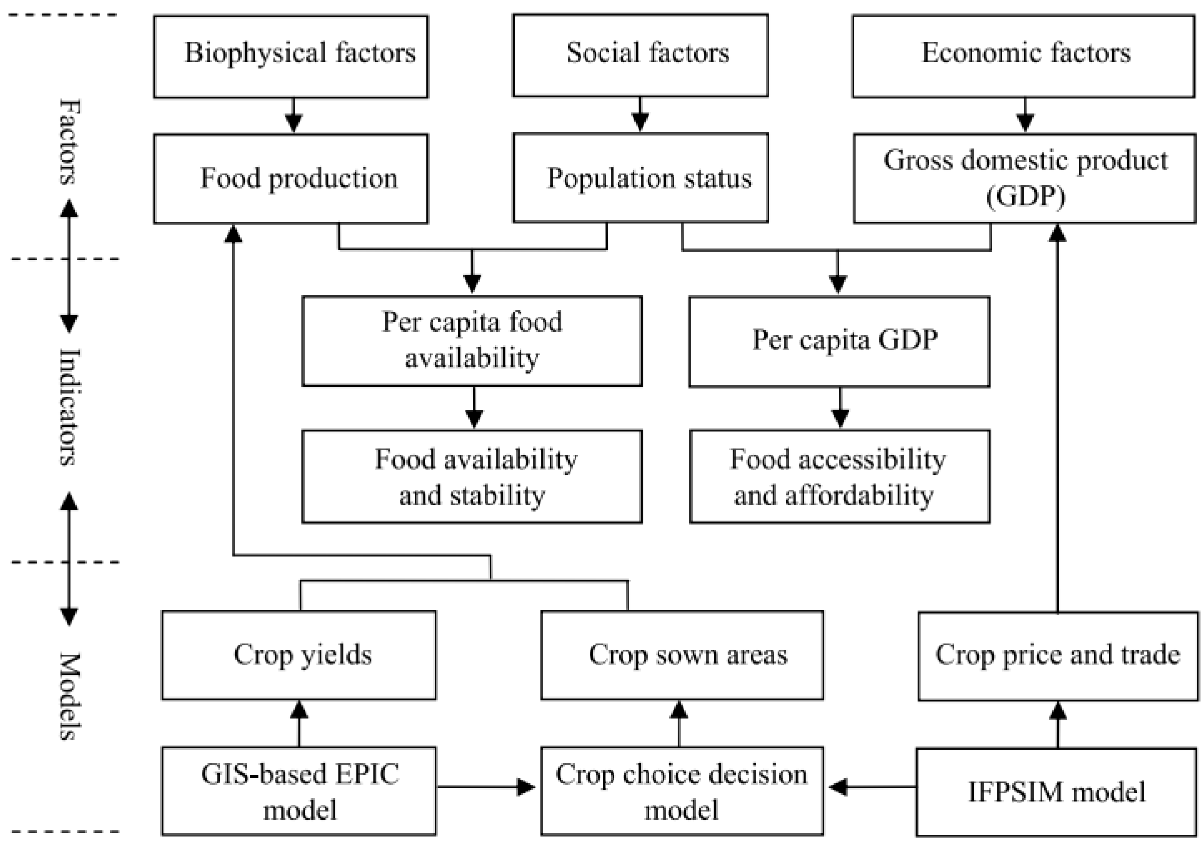
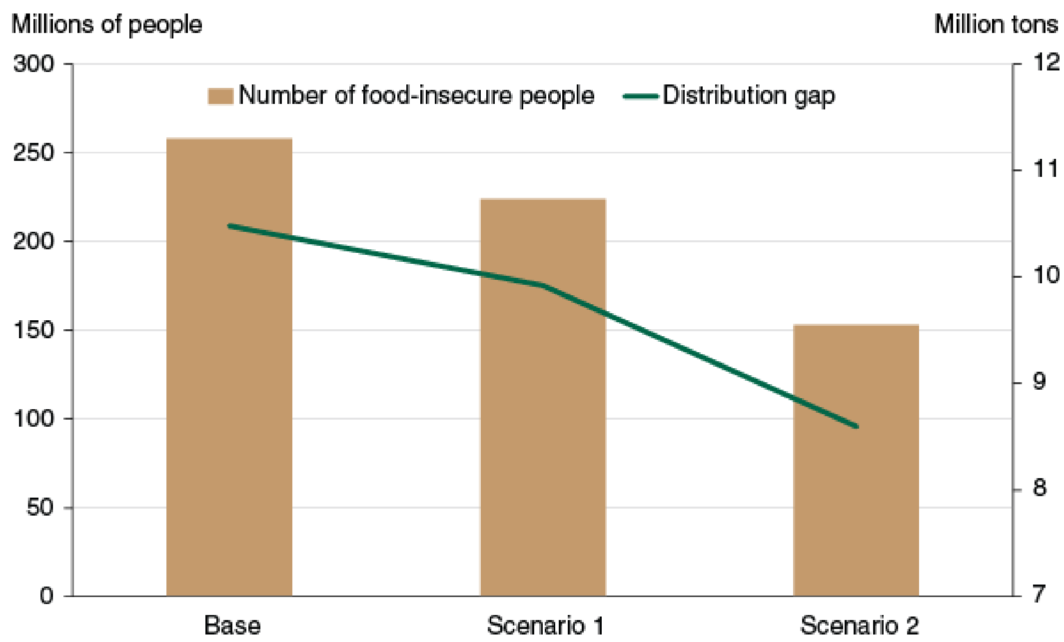
Appendix A: Framework for spatially explicit assessment of potential future risks of food insecurity



Source: Wu et al., 2011, *Global-scale assessment of potential future risks of food insecurity*

Appendix B: Food security is believed to improve as countries devote more crop area to modern varieties



Note: In Scenario 1, the percentage of land devoted to modern varieties (MVs) in each country is assumed to rise to subregional average. In Scenario 2, the percentage of land devoted to MVs in each country is assumed to match that achieved by the country with the highest area devoted to MVs.
Source: USDA, Economic Research Service calculations.

Source: Rosen, S., Fuglie, K., Rada, N., & Meade, B. (2014). *Productivity Impacts on Food Security in Sub-Saharan Africa*.