

# EXPOSURE TO CLIMATE AND VULNERABILITY TO FOOD INSECURITY IN ETHIOPIA

Sara Aregai Ghebremicael

A thesis submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Geography department in the University of North Carolina at Chapel Hill.

Chapel Hill  
2023

Approved by:

Clark Gray

Heather Randell

Erika Wise

© 2023  
Sara Aregai Ghebremicael  
ALL RIGHTS RESERVED

## **ABSTRACT**

Sara Aregai Ghebremicael: Exposure to climate and vulnerability to food insecurity in Ethiopia  
(Under the direction of Clark Gray)

Food insecurity is increasing in severity, with more than two billion people experiencing a lack of nutritious and affordable food. Research in climate change and food systems has generally emphasized crop production and child anthropometric outcomes, with limited focus on the complex linkages between climate variability, household food security, and gender. This paper examines the impacts of climate on diet diversity and coping mechanisms by drawing on nationally representative longitudinal data from Ethiopia through the Living Standards Measurement Surveys – Intensive Surveys on Agriculture (LSMS-ISA) and multiple measures of food insecurity to address vulnerability and resilience. To measure climate exposures, high-resolution data on rainfall and heat shocks from UCSB’s CHIRPS and CHIRTS<sub>max</sub> will be used at a 5km climate grid (0.05°). A regression of food security outcomes as a function of climate anomalies, gender, controls, and interactions will be used to directly measure inequities across households and vulnerability to food insecurity.

## TABLE OF CONTENTS

LIST OF TABLES.....	v
INTRODUCTION.....	1
PREVIOUS RESEARCH.....	4
STUDY AREA.....	6
METHODS.....	8
RESULTS .....	12
CONCLUSION.....	24
REFERENCES.....	30

## LIST OF TABLES

Table 1: Descriptive statistics for main analysis.....	12
Table 2: Fixed effects regression of climate and control variables on outcomes.....	14
Table 3: Descriptive statistics for supplementary climate measures.....	17
Table 4: Climate effects on food security outcomes.....	18
Table 5: Fixed effects regression of climate on food security by farm size.....	20
Table 6: Climate effects on household income.....	22
Table 7: Climate effects on crop yield outcomes.....	23
Table 8: Child anthropometric outcomes regressed with exposure to climate.....	23

## EXPOSURE TO CLIMATE AND VULNERABILITY TO FOOD INSECURITY IN ETHIOPIA

### **Introduction**

As climate variability increases, low- to middle- income countries will experience impacts to livelihoods and food security. In 2019, the FAO projected a total of 234.7 million people undernourished in Sub-Saharan Africa, with 117.9 million concentrated in Eastern Africa (FAO et al., 2020). As such, all dimensions of food security and crop production are expected to shift with climate variability, affecting availability, access, utilization, and stability. Rainfall irregularity and increasing temperatures threaten food security across Africa through lowered crop yields and adverse negative impacts to health and well-being, along with resulting differentiated adaptation strategies (Baker & Anttila-Hughes, 2020). Rising temperatures and changing precipitation patterns will reduce crop yields, thus impacting food security through price increases and changes in consumption and caloric intake (Hamza & Iyela, 2012; Mekonnen et al., 2021). Potential impacts to net farm revenues and increasing land fragmentation increase vulnerability to climate change among self-sustaining and agriculturally reliant smallholder farmers (Hamza & Iyela, 2012). Fast population growth is similarly connected to declined access to healthcare, higher rates of food insecurity, and resulting health consequences (FAO et al., 2020). However, the direct impacts of climate on food security remain underexamined.

Changes in temperature, unpredictability in weather patterns, flooding, and extended dry seasons are expected to undermine resilience and increase vulnerability (Kassegn & Endris, 2021). Vulnerability is characterized by the exposure to potential harmful stressors and shocks, alongside inadequate capacities to cope with shocks and crises (Bohle, 1994). Conditions of low adaptive capacity and limited infrastructure contribute to vulnerability to climate change within Sub-Saharan Africa (Ofori et al 2021). More than 70% of the population lives in rural regions, and about 85% of the population depends on rainfed agriculture and agricultural activities (Kotir, 2011). Additionally, debt increased significantly in

many low- to middle-income countries during the last decade (FAO et al., 2020). Resultingly, weakened growth projections, increased malnourishment, and a lack of infrastructure continues to undermine food security efforts in many emerging countries (FAO et al., 2020). Vulnerability and resilience to food shortages are largely influenced by household- and individual-level characteristics of well-being, wealth, access to resources, livelihoods, community ties, and other factors impact adaptability to shocks (Bene et al., 2016).

Climate change is anticipated to impact groups differently, dependent on socio-political and economic relations. Climate influences on physical and human capital, along with human health, both directly and indirectly alter food access and availability (Mekonnen et al., 2021). Food security is largely dependent on household composition and access to resources, along with gender. The FAO stated “if women had the same access to productive resources as men, they could increase yields on their farms by 20–30%. This could increase total agricultural output in developing countries by 2.5–4%, which could, in turn, reduce the number of hungry people in the world by 12–17%” (FAO, 2011). These factors could potentially reduce or influence susceptibility to food insecurity.

The growing literature on climate and food security focuses on drought and rainfall, with little attention given to temperature. Similarly, multiple proxies are required to measure food security in its entirety because it is a largely theoretical notion. Previous studies have taken varied approaches, focusing on many aspects of food security. Some studies have examined food security through climate and agricultural conditions (Calzadilla et al., 2013; Malhi et al., 2021; Wang et al., 2020; Zhu et al., 2022; Seo et al., 2009; Pironon et al., 2019; Kotir, 2011; Conway et al., 2015; Brown et al., 2017), while others assessed food security impacts on health, nutrition, livelihood, and childhood (Springmann et al., 2016; Bakhtsiyarava & Grace, 2021; Niles et al. (2020); Baker & Anttila-Hughes, 2020; Randell et al., 2020; Baye & Hirvonen, 2020; Hirvonen et al. 2021; Aurino et al. 2019; Thiede et al, 2020). Few studies have examined the relationship between food security and climate more directly (Randell et al., 2022; Tankari, 2020; Carpena, 2019; Smith & Frankenberger, 2018).

This paper builds on our previous research that has measured impacts of climate exposure on individual and household level outcomes, including educational achievement, nutritional status, and migration. Increased rainfall during the agricultural season and milder temperatures were linked to a greater likelihood of educational attainment (Randell & Gray, 2016); while exposure to higher temperatures during the prenatal and early-life period was connected to fewer years of schooling in Southeast Asia (Randell & Gray, 2019). Higher-than-average temperatures were also found to increase malnourishment in adult populations (Mueller & Gray, 2018) and stunting in children (Nicholas et al., 2021), while increased precipitation was found to be beneficial for child health (Nicholas et al., 2021). Along with impacts to educational attainments and nutrition, climate anomalies are also connected to context-specific migration patterns. Gray & Wise (2016) measured internal and international migration across Kenya, Uganda, Nigeria, Burkina Faso, and Senegal – finding country-specific effects of climate variability on migration. This indicates potential later-life challenges for individual health and development, and can shape household decision-making processes.

This research is also situated within the emerging field of climate, food security, and nutrition, while directly addressing gaps in current studies – namely through the direct measurement of vulnerability and resilience of food security to climate shocks; and by using five measures of food security. This paper examines the role of rainfall and temperature variability on food security in Ethiopia. Ethiopia is experiencing higher annual variability of climate extremes (Gebrechorkos, et al., 2019), and the prevalence of moderate to severe food insecurity in the total population was 56.2%, while the prevalence of stunting in children under 5 is 35.3% (FAO, 2022). Drawing on publicly available and nationally representative household survey data from the World Bank’s Living Standards Measurement Surveys – Intensive Surveys on Agriculture (LSMS-ISA) from Ethiopia, where households are tracked and re-interviewed every ~2 years, we link high resolution gridded climate datasets to survey data to measure impacts of variation in climate on food security. A fixed effects regression of food security outcomes is used to assess how climate variability is associated with five measures of food security,



including: Household Dietary Diversity Score (HDDS), Food Consumption Score (FCS), Coping Strategies Index (CSI), reduced Coping Strategies Index (rCSI), and months of inadequate food.

### **Previous Research**

The link between climate variability and agriculture has been thoroughly investigated, showing that variability in climate impacts all aspects of agricultural production. Changes in precipitation, temperature, and river flow are linked to global declines in agricultural production, welfare, and GDP – with less vulnerability seen in irrigated crops (Calzadilla et al., 2013). Climate variability threatens declines in productivity through pest infestations, weakened irrigation technologies, and changes to soil fertility and plant physiology globally (Malhi et al., 2021). Similarly, increases in temperature are associated with reductions in major crop yields, specifically among maize, rice, and soybean (Wang et al., 2020). Changes in rainfall patterns, temperature, and weather extremes are expected to negatively impact cropping area, length of growing seasons, and yield potential across Sub-Saharan Africa (Kotir, 2011). Zhu et al. (2022) find a negative relationship between warming, cropping frequency, and caloric yield, with decreased cropping frequency likely to intensify global crop production loss.

Climate variability will continue to have regionally- and seasonally specific effects across Africa – with overall trends indicating temperature increases will bring harm to agricultural net revenues, and increases in precipitation could benefit or harm agricultural production dependent on regional characteristics (Seo et al., 2009). Pironon et al. (2019) find a greater possibility of production insecurity for a variety of crops across Sub-Saharan Africa, with an increased potential for adaptation methods such as crop substitution. Models for Southern Africa anticipate changes in annual precipitation, with a 20% maximum decrease by the 2080s, and reduced water availability that will consequently impact crop yields (Conway et al., 2015). Similarly, East Africa is experiencing increased variability in rainfall: central and eastern Ethiopia have seen declines of ~0.4 to -0.6 units in the Standardized Precipitation Index (SPI), while northern Ethiopia has seen increases during the growing season (Brown et al., 2017). Brown et al. (2017) find associations between reductions in rainfall across Ethiopia during the growing season and

sub-seasonal crop water stress, resulting in cropland degradation near the eastern highlands. The well-explored research on climate and agriculture shows regionally specific impacts of climate variability, with large global reductions to agricultural production.

Climate and agricultural production are also linked to nutrition and livelihoods through multiple pathways. Springmann et al. (2016) used global and regional agricultural modelling frameworks to link health and future food production under climate change scenarios, finding expected lower caloric availability and increased malnourished individuals. Studies focusing on climate and impacts to health and nutrition have found children to be most vulnerable – with greater likelihood of stunting, wasting, and developmental impacts. Increased diversification of agricultural production results in a reduced risk of stunting amongst children in Ethiopia (Bakhtsiyarava & Grace, 2021). Niles et al. (2020) find that long-term and short-term increases in temperature are significantly and negatively associated with child dietary diversity across 19 countries. Across Sub-Saharan Africa, high ambient temperatures during the growing season are significantly associated with acute health problems in children and resultant weight-loss (Baker & Anttila-Hughes, 2020). In Ethiopia, less than 30% of children meet minimum dietary diversity standards, of which, 20% of rural children and 10% of urban children show signs indicative of stunting at birth (Baye & Hirvonen, 2020). Drought in the first two years of life is particularly disadvantageous to child physical development – namely through the increased likelihood of stunting and wasting (Dimitrova, 2021). Randell et al. (2020) found in utero and early life conditions significantly impact nutritional outcomes, particularly as temperature during the prenatal period increases. Thiede et al. (2020) found women's exposure to variation in temperature and precipitation within a 36-month period linked to fertility rates, with above-average temperature and below-average precipitation associated with a lower likelihood of experiencing a live birth in the following year within Sub-Saharan Africa. Additionally, early life conditions are fundamental to later life achievements. Randell & Gray (2016) found a relationship between early life climate and educational attainment for Ethiopian children, indicating impacts to socio-economic status. Similarly, Aurino et al. (2019) find evidence indicating early-life conditions are significantly associated with later-life learning achievements. Climate conditions are

connected to health and wellbeing through many pathways, with children facing the greatest vulnerability for undernutrition

Food security is comprised of four components – availability, access, utilization, and stability – all of which are likely to be impacted by climate change. The growing literature concerning climate and food security is limited, and largely focuses on drought and rainfall with few considerations of temperature. Randell et al. (2022) find food access and availability to be sensitive to rainfall conditions in Tanzania, with households that experienced greater rainfall more likely to be food secure. Similarly, increases in rainfall in Burkina Faso are linked to reductions in household level food insecurity among farm households (Tankari, 2020). Droughts exacerbate food insecurity through impacts to agricultural availability, food spending, macronutrient intake, and dietary diversity (Carpena, 2019). Increasing impacts of climate on food security and nutritional status are inherently tied to household level characteristics. Gender of the household head and socio-economic status are significant factors in determining vulnerability to rainfall anomalies (Randell et al., 2022). Vulnerability is also dependent on non-farm enterprises, as alternative livelihoods help mitigate impacts of rainfall variability and reductions in food availability and access (Tankari, 2020). Additional factors that play a role in lowering vulnerability and increasing resilience include access to social capital, human capital, safety nets, assets, and access to markets (Smith & Frankenberger, 2018; Randell et al., 2021). The many components of food security make it a difficult concept to conceptualize, and therefore it remains understudied.

### **Study Area**

Agriculture accounts for 42% of Ethiopia's GDP, and about 85% of export earnings (FAO, 2016). About 80% of the population of Ethiopia is dependent on agriculture, primarily smallholders on rainfed lands using traditional farming techniques, a population increasingly vulnerable to seasonal fluctuations (Hamza & Iyela, 2012; Mekonnen et al., 2021; Conway & Schipper, 2011). Smallholder farming practices dominate the agricultural sector, with 95% of the country's agricultural products produced by 12

million smallholder households and 93% of households practicing agriculture (FAO, 2011). Population well-being is therefore sensitive to fluctuations in rainfall and temperature.

Climatic conditions in Ethiopia range from semi-arid to tropical monsoon, with wet highlands and arid lowlands characterized by high seasonal and interannual variability (Choi et al., 2022; Gebremeskel et al., 2019). There are two rainy seasons – Belg and Meher/Kiremt, and one dry season – Bega. Belg characteristically runs from February through May; Meher tends to run from June through September; and Bega typically runs from October through January. Crops are typically harvested during the dry winter season (Bega), accounting for ~90-95% of production (Bezabih & Di Falco, 2012). Climate variability during the Kiremt and Bega seasons consequently have the greatest impacts on harvests. Climate records have suggested rapid warming at a quicker rate than the global mean in East Africa – causing more frequent intensified heatwaves and rainfall variability (Choi et al., 2022).

Ethiopia is highly vulnerable to climate variability and is one of the most drought-prone countries in the world (OCHA, 2023). In 2015, the country experienced the worst drought in decades, with 15% of the population resultingly considered chronically food insecure and 10.2 million people in need of emergency assistance (USAID, 2016). Additionally, higher temperatures dramatically increased the prevalence of crop pests, leading to damaged crops and pastures (FAO, 2021; Campbell et al., 2016). The 2016 Ethiopian Demographic and Health Survey reported 38% of children under the age of 5 are stunted (short for age), 10% are wasted (thin for height), and 24% are underweight (thin for age) (CSA & ICF, 2016). In 2019, a surge in desert locusts drastically damaged crops, pastures, and many other forms of groundcover – contributing to the already intensified dire food security position of the country (FAO, 2021). Soon after, drought conditions began in late 2020 and have continued into 2023, resulting in a multi-year failed rainy season (OCHA, 2023). Conflict has similarly contributed to food insecurity in the northern and southern regions of Ethiopia, with resulting emergency famine conditions. About 21% of the population of Ethiopia is considered acutely food insecure and in need of emergency assistance; and the number of children experiencing wasting has also increased by 14% from 2021 to 2022, with increases also expected in 2023 (FAO & WFP, 2023).

## **Methods**

To measure climate effects on food security, we link data from the World Bank's Living Standards Measurement Survey – Intensive Surveys on Agriculture (LSMS-ISA) to high-resolution data on rainfall and heat shocks. The LSMS-ISA collects nationally representative longitudinal household data in which households are tracked and re-interviewed every ~2 years for 3 waves (Carletto & Gourlay, 2019). It's multi-topic, integrative nature allows for a comprehensive understanding of agriculture and its connection to aspects of well-being, including household composition, education, living standards, health, household assets, expenditures, nonfarm income, coping strategies, and access to services (Gebremariam & Tesfaye, 2018).

These surveys interviewed 4,000 households from rural and small towns, with surveys implemented in 290 rural and 43 small-town enumeration areas (Hengsdijk & De Boer, 2017). All interviews were conducted from May through June, and we use three rounds of survey data from 2011, 2013, and 2015. The 2013 survey data was expanded to include urban households, but these were excluded from our analysis for consistency purposes. All survey waves include information on food security, household and individual level characteristics, and finances (Carletto & Gourlay, 2019). These data are used to define the outcome and control variables. The baseline sample was selected through multi-stage cluster sampling, and our analysis includes the use of sample weights. Cluster-level location information is available for 330 clusters, which was then randomly offset by GPS to 2-10km. We will also include child anthropometry measurements for children under 5 in our analysis, used to measure stunting and wasting.

Food security was operationalized through five measures: the household dietary diversity score, the food consumption score, the coping strategies index, the reduced coping strategies index, and months of inadequate food. The food consumption score (FCS) is a composite score established by the World Food Programme that incorporates dietary diversity, food frequency, and nutritional importance of different food groups (World Food Programme, 2009). A higher score indicates greater dietary diversity and food frequency, demonstrating higher food security. Information comes from a country-specific list

of food items, with which a household recounts frequency of consumption for each item over a seven-day period – which is then placed into 8 food groups and multiplied by an assigned nutrient weight (Food Consumption Analysis, 2008). The summed values then provide an FCS score. Thresholds allow for the categorization of households as having poor, borderline, or acceptable food consumption (Lovon & Mathiassen, 2014). A validation study executed by the International Food Policy Research Institute (IFPRI) analyzed calorie consumption survey data from three countries – Burundi, Haiti, and Sri Lanka (Wiesmann et al., 2009). The study found positive and statistically significant correlations between FCS and calorie consumption per capita, indicating the usefulness of FCS as an indicator of food security. Limitations associated with this indicator include its seven-day recall period – which doesn't provide a full picture of longer periods, in addition to a lack of information on changes in diet resulting from shocks. Lovon & Mathiassen (2014) also perform a validation study calculating FCS from 6 countries, finding significant but not highly correlated associations with caloric intake. Overall, multiple studies have found evidence of the advantages of using Food Consumption Score as an indicator of Food Security, while also finding limitations.

The household dietary diversity score (HDDS) is a measure of the number of different food groups consumed to capture nutritional value and the overall socio-economic status of the household (Swindale et al., 2006). HDDS is a proxy indicator of food access, developed by the Food and Nutritional Technical Assistance Project (Wiesmann et al., 2009). As defined by the World Food Program (2007), dietary diversity is “the number of different foods or food groups eaten over a reference time period, not regarding the frequency of consumption”. HDDS accounts for intake through a qualitative ‘free’ 24-hour recall period used to assess diversity in food groups consumed by a household (Kennedy et al., 2010). Determination of whether the 24-hour recall period was usual or normal for a household is required, and responses should only include food groups consumed by household members within the household. Food items are then aggregated into 12 food groups, in which all groups are weighted the same. HDDS is then obtained by taking the sum of the number of food groups consumed. This indicator reflects the number of different food groups consumed – highlighting diversity in macro- and micronutrient content, and is also

used as a proxy measure of socio-economic status of the household (Swindale & Blinksy, 2006). A validation study conducted by Hoddinott & Yohannes (2002) examined the usefulness of dietary diversity in measuring household food access across ten country datasets. Their findings indicate the association between dietary diversity and household per capita caloric availability increases with the level of household per capita caloric availability, showing advantages in using HDDS as a means of measuring and monitoring changes in food access.

The coping strategies index (CSI) seeks to answer the question: “what do you do when you don’t have enough food, and don’t have enough money to buy food” (Coping Strategies Index, 2008). Behavioral responses to periods of insufficient food are measured via the frequency of coping strategies. Coping strategies are not equal in severity, and can reveal periods of hardship and food insecurity – as such, coping strategies are multiplied by a weight that reflects severity, and scores are combined into a single score (World Food Programme, 2009). A recall period of seven days is recommended. A validation study by Maxwell et al. (1999) found significant correlations between CSI and other indicators of food security such as dietary intake (kilocalories per adult equivalent per day), percapita expenditure, and the proportion of expenditure on food (food budget shares). CSI is a context-specific indicator of food insecurity, and lacks comparability across regions (Maxwell & Caldwell, 2008). However, a more comparable ‘reduced’ CSI (rCSI) was developed based on the most prevalent coping behaviors indicated. While CSI relies on context-specific strategies and context-specific severity scores – making it more valuable in identifying most vulnerable households, rCSI relies on the same five pre-weighted coping strategies (Maxwell & Caldwell, 2008). The rCSI is therefore comparable across different contexts and regions, and can be used as an indicator of severity of shocks and variability in resources across context (World Food Programme, 2009).

The final measure is a count of the number of months of insufficient food in the prior year, a direct measure of the duration of food insecurity. Months of insufficient food is a subset of Africare’s Months of Adequate Household Food Provisioning (MAHFP) indicator, which is used to identify vulnerable groups, build intervention strategies, and track progress in improving food security (Konda et

al., 2008). Through this measure, seasonal differences in food provision and economic access can be examined. Data is best collected during periods of greatest food shortage, and the number of months of inadequate food is summed up over the span of 12 months. This can be used to track patterns and duration of fluctuation, particularly those related to seasonal or cyclical shifts in food security (Blinksy & Swindale, 2007). Ultimately, all five measures provide a well-rounded, quantifiable assessment of food insecurity.

CHIRPS and newly available CHIRTS<sub>max</sub> from UCSB Climate Hazards Center are available at a 5km climate grid (0.05°), integrated from both satellites data and weather stations. A monthly time-series of climate data was extracted to the LSMS clustered locations to 10 km radius buffers as a spatial mean of pixels within the buffer. Monthly climate data was converted into season-specific 24-month running means, and for supplementary analyses also into 12-month running means and z-scores standardized by the local historical mean and standard deviation (standardized climate anomalies). This allows for lags between harvest failures and consequent impacts to food security and health. Precipitation and temperature were considered for the three seasons – Belg, Kiremt, and Bega – with differing lag times to distinguish changes in climate. We also considered impacts of climate extremes. In defining climate extremes, we designated four categories with 0–23-month lag times – very wet days, dry days, very hot days, and very cold days. Very wet, very hot, and very cold days were defined by the 95<sup>th</sup> percentile in precipitation and temperature. Dry days are defined as days with zero precipitation.

Fixed effects linear regressions of food security outcomes as a function of climate anomalies, gender, and controls were estimated. Our approach accounts for clustering in the survey data by enumeration id. Fixed effects were included for clusters and survey wave. Cluster fixed effects account for time-invariant characteristics of the locations. Survey wave fixed effects account for the national-scale time-varying contexts. The first set of models examine the relationship between climate anomalies and food security outcomes, controlling for socio-economic, demographic factors, and time-invariant factors. Time invariant factors include immutable location characteristics, including elevation, soil type, and distance to urban areas. Socio-economic and demographic controls include sex, age in months, and



household characteristics – farm size, improvements in roof structure, wave, enumeration ID, and household head controls (education and age). The second set of models measures the relationship between climate extremes and food security outcomes. The third set of models are supplementary models which include 12-month exposures, stratification by farm size, income/yields as outcomes, and child anthropometric measurements on a separate sample of children under 5. Height-for-age z-score (HAZ) and weight-for-height z-score (WHZ) were used as child anthropometric outcomes. To examine the relationship between climate and child development, we use a set of controls, including sex, age in months, and household characteristics – farm size, improvements in roof structure, wave, enumeration ID, along with maternal controls (education, age, and height). We hypothesize that increased temperatures and greater variability in rainfall will decrease food access and increase malnutrition, resulting in conditions of increased vulnerability and decreased resilience.

## **Results**

Descriptive statistics are presented in Table 1. Sample size, mean, standard deviation, and minimum/maximum values are listed for all variables. Food security outcomes and season-specific 24 month running means are highlighted, along with demographic and socio-economic household characteristics. Demographic variables include the age and gender of the household head, and the age of household members. Socio-economic variables include farm size and roof structure. Descriptive statistics are also presented for each wave. Data for 11,390 households were connected to climate data for three waves of interviews.

**Table 1:** Descriptive statistics for main analysis.

	Obs	Mean	Std. Dev.	Min	Max
FCS	11,190	41.38	20.60	0.5	112
CSI	11,045	1.992	6.823	0	105
rCSI	11,045	1.204	3.868	0	56
Months Inadequate Food	11,045	0.965	1.849	0	12

HDDS	11,390	5.571	1.736	0	11.00
Precip. Kiremt (mm)	11,390	13.16	6.382	0	30.01
Precip. Belg (mm)	11,390	5.845	3.327	0.332	17.59
Precip. Bega (mm)	11,390	2.754	2.197	0.006	11.54
Temp. Kiremt (C)	11,390	26.01	3.695	18.11	39.84
Temp. Belg (C)	11,390	28.47	3.555	20.62	40.82
Temp. Bega (C)	11,390	27.02	3.168	19.95	39.58
Number of Members Age 0-6	11,390	1.007	1.070	0	6
Number of Members Age 7-15	11,390	1.396	1.306	0	8
Number of Members Age 16-64	11,390	2.304	1.262	0	10
Number of Members Age 65+	11,390	0.194	0.438	0	3
Farm Size 0ha	11,390	0.165	0.371	0	1
Farm Size >0-1ha	11,390	0.481	0.500	0	1
Farm Size >1-2ha	11,390	0.194	0.396	0	1
Farm Size >2-4ha	11,390	0.117	0.322	0	1
Farm Size >4+ha	11,390	0.042	0.202	0	1
Urban	11,390	0.120	0.326	0	1
Head Male	11,390	0.739	0.439	0	1
Head Female	11,390	0.258	0.438	0	1
Head Gender Missing	11,390	0.002	0.050	0	1
Head Age 8-29	11,390	0.142	0.349	0	1
Head Age 30-39	11,390	0.264	0.441	0	1
Head Age 40-49	11,390	0.226	0.418	0	1
Head Age 50-59	11,390	0.153	0.360	0	1
Head Age 60-69	11,390	0.211	0.408	0	1
Head Age Missing	11,390	0.003	0.058	0	1
Non-improved Roof	11,390	0.516	0.500	0	1
Improved Roof	11,390	0.483	0.500	0	1
Roof Type Missing	11,390	0.001	0.030	0	1
Wave 1	11,390	0.344	0.475	0	1
Wave 2	11,390	0.331	0.471	0	1
Wave 3	11,390	0.325	0.468	0	1

Table 2 presents the main fixed effects regression analysis examining the effects of climate exposures and control variables on food security outcomes. Joint tests of significance for climate variables on food security outcomes were significant at the  $p=0.001$  for coping strategies, reduced coping strategies, and months of inadequate food. Household dietary diversity was significantly linked to climate exposures at the  $p=0.05$  level. Increases in rainfall during Kiremt were associated with increased months of adequate food ( $p=0.000$ ). Increased temperatures in Kiremt and Belg resulted in negative food security outcomes, with Kiremt associated with increased use of reduced coping strategies ( $p=0.036$ ), and Belg associated with increased months of inadequate food ( $p=0.001$ ). Contrastingly, higher temperatures in Bega positively contributed to household dietary diversity scores ( $p=0.003$ ) and were linked to a declined necessity of reduced coping strategies ( $p=0.037$ ); while higher amounts of precipitation resulted in greater use of coping strategies (CSI) ( $p=0.001$ ) and reduced coping strategies (rCSI) ( $p=0.000$ ), and led to increases in the number of months of food insufficiency ( $p=0.044$ ). Food security outcomes are also linked to socio-demographic characteristics of the household and the household head. For example, female headed households experience more months of insufficient food than male-headed households ( $p=0.001$ ), making this group more vulnerable to impacts to food security.

**Table 2:** Fixed effects regression of climate and control variables on outcomes. Table includes controls for wave, enumeration ID, clustering, and weights.

	FCS	CSI	rCSI	Months Inadequate Food	HDDS
Precip. Kiremt (mm)	-0.180	0.122	0.020	-0.228***	-0.001
Precip. Belg (mm)	-0.529	0.212	0.147	0.002	-0.018
Precip. Bega (mm)	0.843	1.441***	0.817***	0.265*	0.037
Temp. Kiremt (C)	-0.802	4.407+	2.547*	-0.329	-0.287
Temp. Belg (C)	2.884	1.66	1.248+	0.705***	-0.247
Temp. Bega (C)	0.505	-4.957+	-3.057*	-0.329	0.800**
Head Male	0.000	0.000	0.000	0.000	0.000
Head Female	-0.069	0.142	0.073	0.198***	-0.078
Head Gender Missing	10.00	3.376+	1.835*	0.281	-1.142+
Head Age 8-29	0.000	0.000	0.000	0.000	0.000
Head Age 30-39	-1.059	0.396	0.295+	0.186**	-0.054

Head Age 40-49	-2.572**	0.700*	0.425*	0.297***	-0.250**
Head Age 50-59	-2.425*	0.647+	0.384*	0.201*	-0.228**
Head Age 60-69	-1.882*	0.542	0.403+	0.235*	-0.234**
Head Age Missing	-20.64**	0.702	0.485	-0.155	0.150
Head No Educ .	0.000	0.000	0.000	0.000	0.000
Head Educ. 1-4	2.170**	-0.021	-0.073	-0.079	0.191**
Head Educ. 5+	3.619***	-0.649**	-0.364**	-0.336***	0.477***
Head Educ. Missing	4.371*	-1.459	-0.751	-0.135	0.378+
Number of Members Age 0-6	0.165	0.211*	0.195**	0.072**	0.057**
Number of Members Age 7-15	0.350*	0.048	0.032	0.012	0.040*
Number of Members Age 16-64	0.935***	-0.158**	-0.083*	-0.012	0.131***
Number of Members Age 65+	-0.231	0.127	-0.010	0.125+	0.060
Farm Size 0ha	-2.768	1.060+	0.793*	0.567***	-0.616***
Farm Size >0-1ha	-4.684**	0.800*	0.511*	0.501***	-0.561***
Farm Size >1-2ha	-2.010	0.389	0.255	0.246**	-0.348***
Farm Size >2-4ha	-2.553+	-0.012	0.010	0.075	-0.178*
Farm Size >4+ha	0.000	0.000	0.000	0.000	0.000
Non-improved Roof	0.000	0.000	0.000	0.000	0.000
Improved Roof	3.297***	-0.606***	-0.374***	-0.348***	0.424***
Roof Type Missing	9.824***	-3.643*	-1.743+	0.030	-2.092
Urban	2.717	2.245	1.070	-1.811	0.167
Wave 1	0.000	0.000	0.000	0.000	0.000
Wave 2	5.286**	-6.403***	-3.477***	0.225	-0.027
Wave 3	5.466***	-6.126***	-3.222***	0.289	0.913***
N	11190	11045	11045	11045	11390
Prob > F	0.517	0.001***	0.001***	0.000***	0.037*

Age of the household head was also significantly associated with food security outcomes, controlling for all other variables (Table 2). Household heads 40+ were linked to declines in FCS and HDDS, along with more months of inadequate food in comparison to the reference category – those between 8 and 29 years old. Household heads aged 30-39 were also linked to more months of insufficient food. Those in 40s were linked to higher CSI and rCSI, and those in the 50s were linked to higher rCSI. The five outcomes are also significantly impacted by household member age composition. Food consumption score and household dietary diversity increases for households composed of members 7-15 and 16-64 years old. Additionally, for households with members 16-64, we find a significant reduction in

CSI, rCSI, and months of inadequate food. Those containing members 0-6 years old, saw increases in CSI, rCSI, months of inadequate food, and household dietary diversity score. Intuitively, younger children and the elderly might be most vulnerable to negative food security outcomes. Like age groups, education of the household head influences food security status of a household. The reference category refers to household heads who have completed no education, kindergarten, or first grade. Having an education of up to 4<sup>th</sup> grade shows a significant increase in FCS and HDDS. Those with an education level of 5<sup>th</sup> grade or higher saw greater food consumption and household dietary diversity scores, and decreases in CSI, rCSI, and months of inadequate food in comparison to the reference category. Generally, higher education levels of the household head are connected to better food security outcomes. Along with education of the household head, age can impact food security. Our results indicate a connection between higher ages of the head of the household, and vulnerability to lower food security outcomes. In addition to age of the household head, households composed of young children and the elderly are similarly vulnerable to negative outcomes.

Additionally, variables that reveal socio-economic status, like farm size and improved roofs, can indicate how a household might mitigate exposure to variation in climate. Controlling for all other variables, a household with no farmland sees greater use of reduced coping strategies, more months of inadequate food, and declined household dietary diversity in comparison to the reference category – having 4+ ha of land. Those with 0-1 ha of farmland see lower FCS and HDDS, increased CSI and rCSI, and increased months of inadequate food. Having 1-2 ha of farmland increases months of inadequate food and decreases household dietary diversity. Having 2-4 ha of farmland also results in a reduction of HDDS. Overall, the negative correlation between farmland and household food security declines with access to more land. The same is true of having an improved roof, resulting in greater FCS and HDDS, and declines in CSI, rCSI, and months of inadequate food.

**Table 3.** Descriptive statistics for supplementary climate measures, climate extremes, income, crop yield, and child anthropometric outcomes including standardized climate anomalies and 12-month climate exposures.

Variable	Obs	Mean	Std. Dev.	Min	Max
Precip. Kiremt (mm) 0-11 mo	11,390	6.813	3.151	0.000	15.09
Precip. Belg (mm) 0-11 mo	11,390	2.839	1.622	0.143	8.461
Precip. Bega (mm) 0-11 mo	11,390	1.135	0.915	0.000	7.268
Temp. Kiremt (C) 0-11 mo	11,390	25.97	3.677	17.94	39.86
Temp. Belg (C) 0-11 mo	11,390	28.28	3.535	20.66	40.59
Temp. Bega (C) 0-11 mo	11,390	27.26	3.214	20.11	40.06
Precip. Kiremt (mm) 0-23 mo	11,390	13.16	6.382	0.000	30.01
Precip. Belg (mm) 0-23 mo	11,390	5.845	3.327	0.332	17.59
Precip. Bega (mm) 0-23 mo	11,390	2.753	2.197	0.006	11.54
Temp. Kiremt (C) 0-23 mo	11,390	26.01	3.695	18.11	39.84
Temp. Belg (C) 0-23 mo	11,390	28.47	3.555	20.62	40.82
Temp. Bega (C) 0-23 mo	11,390	27.02	3.168	19.95	39.58
Very Wet Days	11,390	37.42	5.969	22.00	57.00
Dry Days	11,390	521.4	58.73	327.0	686.0
Very Hot Days	11,390	43.61	11.93	16.00	91.00
Very Cold Days	11,390	28.37	11.21	2.000	65.00
Per Capita Consumption	10,949	8.194	0.699	5.866	12.04
Crop Income	7,499	7.907	1.574	0.652	14.71
Animal Income	7,317	7.664	1.758	0.693	16.57
Non-farm Income	6,577	7.947	1.698	0.693	16.38
Maize Yield	3,750	7.148	1.223	0.057	14.26
Wheat Yield	1,766	6.912	1.049	0.304	11.94
Sorghum Yield	2,701	6.728	1.174	0.714	11.68
Teff Yield	2,569	6.303	1.035	1.279	9.907
Barley Yield	1,640	6.736	1.145	0.592	13.74
HAZ	6,436	-1.569	1.978	-6.000	5.943
WHZ	6,264	-0.426	1.523	-5.970	5.920
Age in Months	6,606	32.97	15.34	0.000	59.00
Child Gender	6,606	1.485	0.499	1.000	2.000

Descriptive statistics of supplementary variables are presented in Table 3. While the main analysis focuses on season-specific 24-month running means, the supplementary analyses consider associations between food security and both 12-month running means and climate anomalies. 12-month running means explain relationships between a one unit increase in temperature or precipitation, and changes in food security. Climate anomalies are standardized relative to historical standard deviations. Therefore, as climate values move away from the historical mean in terms of standard deviations, we examine changes to food security.

Table 4 displays a set of supplementary fixed effects linear regression models of climate exposures on food security outcomes. Climate anomalies impact food security to varying degrees, dependent on seasonality and household level characteristics. 12-month climate exposures were notably associated with changes in CSI, rCSI, and months of inadequate food. Greater rainfall during Bega resulted in significant increases in the coping ( $p=0.001$ ) and reduced coping strategy indices ( $p=0.000$ ), in addition to increasing months of inadequate food ( $p=0.000$ ) and decreases in household dietary diversity scores ( $p=0.018$ ). Decreases in months of inadequate food were connected to higher temperatures in Kiremt, while increases in months of inadequate food were linked to higher temperatures in Bega ( $p=0.031$ ).

**Table 4.** Climate effects on food security outcomes. 12-month exposures and standardized climate anomalies are displayed, along with extreme weather conditions. Controls include gender, age, and education of the household head, age of household members, farm size, roof conditions, rural/urban status, wave, enumeration ID, clustering, and weights.

12 mo	FCS	CSI	rCSI	Months Inadequate Food	HDDS
Precip. Kiremt (mm)	0.716	0.130	0.032	-0.145	-0.014
Precip. Belg (mm)	-1.398+	-0.512	-0.288	-0.090	0.004
Precip. Bega (mm)	2.22	3.422***	1.959***	0.731***	-0.267*
Temp. Kiremt (C)	-2.643	1.189	0.647	-0.976*	-0.052
Temp. Belg (C)	-1.723	-1.548	-0.782	0.187	-0.020
Temp. Bega (C)	3.951	0.386	0.291	0.381*	0.142
N	11190	11045	11045	11045	11390
Prob > F	0.203	0.009**	0.005**	0.009**	0.019*

### Anomalies

Precip. Kiremt (mm)	-0.448	-0.114	-0.149	-0.269**	0.027
Precip. Belg (mm)	-0.589	0.160	0.117	-0.027	-0.054
Precip. Bega (mm)	0.749	1.184**	0.709**	0.264+	0.058
Temp. Kiremt (C)	-0.058	1.693+	0.947*	-0.122	-0.114
Temp. Belg (C)	1.703	0.791	0.629	0.361**	-0.178*
Temp. Bega (C)	-0.386	-1.887+	-1.120+	-0.035	0.296**
N	11190	11045	11045	11045	11390
Prob > F	0.635	0.002**	0.001***	0.007**	0.0468

### Extreme days

Very Wet Days	-0.010	0.095+	0.054*	-0.007	-0.002
Dry Days	-0.010	0.007	0.004	0.004	-0.001
Very Hot Days	0.021	-0.045+	-0.018	0.011*	-0.002
Very Cold Days	0.019	0.123*	0.067*	-0.014	0.001
N	11190	11045	11045	11045	11390
Prob > F	0.978	0.103	0.095	0.068	0.913

Standardized (24-month) climate anomalies were significantly linked to changes in CSI, rCSI, months of inadequate food, and HDDS (Table 4). Increases in the coping strategies index ( $p=.005$ ) and increases in the reduced coping strategies index ( $p=0.003$ ) are associated with higher levels of precipitation in Bega. Increases in the reduced coping strategies index are also associated with higher temperatures in Kiremt ( $p=0.040$ ). Higher temperatures in Belg are connected to a larger number of months of inadequate food ( $p=0.003$ ), and declined household dietary diversity ( $p=0.048$ ). Higher temperatures in Bega, however, resulted in greater HDDS ( $p=0.002$ ). Food security outcomes are driven by climate anomalies; however, food security is not significantly motivated by weather extremes. Identifying climate anomalies by the 90<sup>th</sup> and 95<sup>th</sup> percentile provides insight into how weather extremes can impact food security outcomes. Very cold days increase both CSI ( $p=0.050$ ) and rCSI ( $p=0.039$ ). Similarly, very wet days are linked to higher rCSI ( $p=0.037$ ) and very hot days are linked to increases in the number of months of inadequate food ( $p=0.010$ ). Generally, greater precipitation during the dry months hinders food security outcomes (CSI, rCSI, and HDDS), and while higher temperatures are



harmful in the short-term (increased months of inadequate food), they positively impact household dietary diversity in the long-term. Higher temperatures in Kiremt lower the months of inadequate food in the short-term, but sustained periods of increased heat during the main rainy season results in greater use of reduced coping strategies. Sustained higher temperatures in the short rainy season prove to be detrimental to food security outcomes – lowering household dietary diversity and higher months of inadequate food. While climate extremes are linked to food security outcomes (increased CSI, rCSI, and months of inadequate food), they do not prove to be the main drivers of food insecurity.

**Table 5.** Fixed effects linear regression of climate on food security outcomes by farm size. Controls included for gender, age, and education of the household head, age of household members, farm size, roof conditions, rural/urban status, wave, enumeration ID, clustering, and weights.

0 ha	FCS	CSI	rCSI	Months Inadequate Food	HDDS
Precip. Kiremt (mm)	-0.074	0.772	0.470	-0.191+	-0.108
Precip. Belg (mm)	-0.655	0.368	0.189	-0.057	-0.082
Precip. Bega (mm)	1.387	2.072	1.169	0.427	0.158
Temp. Kiremt (C)	13.25	13.24**	7.047**	-1.460+	-0.227
Temp. Belg (C)	3.896	2.042	0.941	1.159*	-0.382
Temp. Bega (C)	-7.278	-4.456	-2.991	-1.399	1.177
N	1817	1795	1795	1795	1875
Prob > F	0.692	0.033*	0.037*	0.095	0.576
>0-1 ha					
Precip. Kiremt (mm)	0.193	-0.092	-0.155	-0.253**	0.005
Precip. Belg (mm)	-0.726	0.648+	0.366+	0.090	-0.025
Precip. Bega (mm)	-0.036	1.421**	0.785**	0.316	0.027
Temp. Kiremt (C)	0.479	6.260	3.550+	0.131	0.098
Temp. Belg (C)	-3.195	5.139*	3.129*	1.180**	-0.254
Temp. Bega (C)	-1.590	-9.936*	-6.011*	-0.983+	1.238**
N	5376	5335	5335	5335	5482
Prob > F	0.785	0.002**	0.000***	0.016*	0.09
>1-2 ha					
Precip. Kiremt (mm)	-0.192	0.100	0.080	-0.273***	0.014
Precip. Belg (mm)	-0.277	0.125	0.127	-0.064	0.042
Precip. Bega (mm)	2.334	0.875+	0.652*	0.453*	0.039

Temp. Kiremt (C)	-2.698	4.378	2.591	-0.577	-0.311
Temp. Belg (C)	6.149+	1.477	1.175	0.644	-0.076
Temp. Bega (C)	5.989	-2.393	-1.381	0.507	0.55
N	2183	2133	2133	2133	2212
Prob > F	0.118	0.453	0.386	0.002**	0.826

>2-4 ha

Precip. Kiremt (mm)	-0.116	-0.005	-0.036	-0.308**	-0.011
Precip. Belg (mm)	-0.551	-0.219	-0.057	-0.114	-0.046
Precip. Bega (mm)	1.474	0.870+	0.544+	0.026	0.046
Temp. Kiremt (C)	-12.33*	1.101	0.797	-0.750	-0.858*
Temp. Belg (C)	4.500	0.370	0.691	0.547*	-0.332
Temp. Bega (C)	9.450	-0.843	-1.052	-0.517	0.178
N	1330	1309	1309	1309	1337
Prob > F	0.024*	0.273	0.239	0.034*	0.441

>4+ ha

Precip. Kiremt (mm)	-1.252	0.182	0.070	-0.309+	-0.053
Precip. Belg (mm)	0.350	0.112	0.139	-0.168	0.065
Precip. Bega (mm)	-3.598	0.611	0.331	-0.215	0.139
Temp. Kiremt (C)	-31.13**	-3.549	-2.41	-0.387	-1.485+
Temp. Belg (C)	14.05**	-1.46	-0.376	-0.018	-0.534
Temp. Bega (C)	4.401	1.785	0.565	-0.016	0.215
N	484	473	473	473	484
Prob > F	0.005**	0.151	0.149	0.584	0.131

Farm size can indicate socio-economic status, while mitigating the impacts of climate shocks on households. Table 5 presents regression results from the main analysis stratified by household farm size. In households with no farm, climate was a substantial driver of the coping strategies and reduced coping strategies used (Table 5). Higher temperatures in Kiremt significantly led to increases in the CSI and rCSI ( $p=0.002$ ). Similarly, higher temperatures in Belg resulted in an increase in months of inadequate food ( $p=0.034$ ). For households with 0 to 1 ha of farmland, climate significantly explained the relationship between farm size impacts to coping strategies, reduced coping strategies, and months of inadequate food. Increases in precipitation during Kiremt increased the number of months of sufficient food ( $p=0.002$ ), and increases in precipitation during Bega significantly lowered CSI ( $p=0.006$ ) and rCSI ( $p=0.005$ ). Increases

in temperature during Belg increased CSI ( $p=0.022$ ) and rCSI ( $p=0.011$ ), and months of inadequate food ( $p=0.004$ ). Increased temperature during the dry season significantly lowered coping strategies ( $p=0.044$ ) and reduced coping strategies used ( $p=0.016$ ), and increased household dietary diversity ( $p=0.004$ ).

Where households have 1 to 2 ha of farmland, climate explains the variation in household dietary diversity score – with increased precipitation in Kiremt significantly lowering months of inadequate food ( $p=0.001$ ). Increased precipitation in the dry season results in greater use of reduced coping strategies ( $p=0.040$ ) and months of inadequate food ( $p=0.041$ ). With 2 to 4 ha of farmland, households are particularly vulnerable to changes in climate. Increased temperature in Kiremt significantly lowers the food consumption score ( $p=0.028$ ) and the household dietary diversity score ( $p=0.046$ ). Higher temperatures in Belg increased the months of inadequate food ( $p=0.045$ ), while greater precipitation in Kiremt lowers the months of inadequate food ( $p=0.006$ ). Lastly, climate significantly explains the variation in food consumption score with households that have four or more ha of farmland. Increased temperature in Kiremt considerably lowers the food consumption score ( $p=0.008$ ), while increased temperature in Bega increases the food consumption score ( $p=0.009$ ). Overall, increased temperature in Kiremt and Belg negatively impact food security outcomes, while increased precipitation in Kiremt positively impacts food security outcomes. The impacts of higher temperatures in Bega on food security remained dependent on access to farmland and size – with largely positive associations to food security outcomes. For households with no farmland, higher temperatures in Bega increased the months of insufficient food – thus hindering food security and increasing vulnerability.

**Table 6.** Climate effects on household income.

	Per Capita Consumption	Crop Income	Animal Income	Nonfarm Income
Precip. Kiremt (mm)	0.018	0.054	0.030	0.070
Precip. Belg (mm)	0.002	-0.110**	-0.026	0.043
Precip. Bega (mm)	0.018	-0.017	0.021	-0.009
Temp. Kiremt (C)	0.222	-0.100	0.190	1.044***
Temp. Belg (C)	0.010	-0.495*	0.057	0.072
Temp. Bega (C)	-0.023	0.412	-0.309	0.163
N	10971	7502	7333	6589

Prob > F	0.618	0.099	0.681	0.008**
----------	-------	-------	-------	---------

**Table 7.** Climate effects on crop yield outcomes.

	Maize Yield	Wheat Yield	Sorghum Yield	Teff Yield	Barley Yield
Precip. Kiremt (mm)	0.017	0.137*	0.075	0.139**	0.171*
Precip. Belg (mm)	0.094+	0.132*	-0.079	0.001	0.149**
Precip. Bega (mm)	0.041	0.029	-0.058	-0.086	0.122
Temp. Kiremt (C)	0.005	0.189	0.012	-0.124	0.212
Temp. Belg (C)	-0.011	0.069	-0.797**	-0.479*	0.211
Temp. Bega (C)	0.266	0.015	0.718*	0.444	0.159
N	3751	1766	2701	2569	1640
Prob > F	0.146	0.081	0.157	0.075	0.032*

**Table 8.** Child anthropometric outcomes regressed with exposure to climate.

	HAZ	WHZ
Precip. Kiremt (mm)	0.115+	-0.053
Precip. Belg (mm)	0.092+	0.025
Precip. Bega (mm)	-0.005	-0.179+
Temp. Kiremt (C)	-0.413	0.214
Temp. Belg (C)	0.032	0.155
Temp. Bega (C)	-0.318	0.198
N	6436	6264
Prob > F	0.043*	0.194

To more directly understand how climate is linked to food security outcomes through crops and economic variables, we regressed climate on both income (Table 6) and crop yield (Table 7). Income was distinguished by per-capita consumption, crop, animal, and non-farm income. Climate was a significant explainer of non-farm income changes with higher temperatures in Kiremt associated with increases in non-farm income ( $p < 0.001$ ). However, higher temperatures ( $p < 0.05$ ) or greater rainfall ( $p < 0.01$ ) in Belg led to a reduction in crop income. The five main crops analyzed were maize, wheat, sorghum, teff, and barley. Increased precipitation in Kiremt and Belg were associated with greater wheat ( $p < 0.05$ ) and barley ( $p < 0.05$ ;  $p < 0.01$ ) yields. Increased rainfall in Kiremt also resulted in greater teff yields ( $p < 0.01$ ), while increased temperatures in Belg resulted in declines in teff yield ( $p < 0.05$ ). Higher temperatures in Belg

were negatively associated with sorghum yields ( $p < 0.01$ ), while higher temperatures in Bega were positively associated to sorghum yields ( $p < 0.05$ ). Conclusively, while rises in temperature or precipitation during the short rains season led to an overall reduction in crop income – largely due to declined teff and sorghum yields – wheat and barley returns seemed to increase with higher-than-normal rainfall. Increases in rainfall during the long rainy season has an overall positive effect on crop yields, namely teff, wheat, and barley. However, increased temperatures during this season led to alternative non-farm forms of income. While our overall model significance tests indicate climate to be a significant driver of stunting ( $p > 0.043$ ), we found no meaningful relationship between climate anomalies and anthropometric outcomes in each of the three seasons (Table 8).

## **Conclusion**

In analyzing how climate impacts food security outcomes in Ethiopia, we find more rainfall in the wet seasons favored food security, while precipitation during the dry season was disadvantageous to food security. These results can be contextualized alongside other relevant studies that investigate changes in temperature and precipitation patterns. Chou et al. (2013) find vertical moisture advection and evaporation positively correlated to increasing precipitation patterns in the wet seasons, whereas positive changes to evaporation and negative vertical moisture advection in the dry season create variability in drying trends. Additional climate models have suggested wet season increases in extreme precipitation and rainfall irregularity, along with summer warming events (Choi et al., 2022; Nikulin et al, 2018; Osima et al., 2018). With projected increases in climate variability, we can correspondingly expect household food security status to be impacted – and thus vulnerability and resilience.

Our results also indicate robust changes in seasonal precipitation and temperature mainly impedes four measures of food security – CSI, rCSI, months of inadequate food, and HDDS. Short and long-term climate exposures can differentially impact food security outcomes due to multiple factors. For 12-month exposures, higher temperature and precipitation in the dry season negatively impacted food security measures, while higher temperatures in the long rainy season proved to be beneficial. Exposure to climate

variability in the dry season can increase the prevalence of disease and crop pests, and can also create difficulty in accessing food sources and income generating activities through heat-related limitations such as heat wave health impacts.

Standardized 24-month climate anomalies reveal higher temperatures in the rainy seasons and increased precipitation in the dry season were detrimental, while higher temperatures in the dry season and greater precipitation in the long rainy season were beneficial to food security outcomes. Sustained higher temperatures in the rainy season can impact crop physiology and crop yield, while greater amounts of precipitation in the dry season can affect accessibility of non-farm incomes. Additionally, climate variability can influence changes to a plant's phenological cycles – which can ultimately impact food security outcomes (Vrieling et al., 2011). As such, exposure to greater precipitation in the wet season and higher temperatures in the dry season over a longer period can prolong favorable crop cultivating conditions.

Our results indicate short-term exposure to temperature anomalies in the rainy season proved to be beneficial, while long-term exposure proved to be detrimental to household food security. Long-term exposures to increases in rainfall during the long rainy season was beneficial for household food security, which can be a result of increased agricultural productivity and diversification, increased opportunity for livestock grazing, better soil quality, and water availability for irrigation. Favorable farming conditions also create opportunities for wet-season employment.

Short-term exposure to increased temperatures can ultimately benefit crop phenology through accelerated growth and development, early maturation, and increases in yield (Gifford, 1995). Long-term temperature exposures in the rainy season can increase water stress and create favorable conditions for pests and disease, resulting in reduced agricultural productivity. Desert locusts, for example, favor semi-arid to arid areas, taking advantage of desert rains – as was the case in Ethiopia where high temperatures and rainy seasons created favorable conditions and breeding grounds (FAO, 2021). Short-term exposures can also be accounted for through coping strategies, but these strategies may not be sustainable in mitigating long-term exposures to climate shocks. In assessing impacts of climate and price volatility on

household income and food security in Ethiopia and Ghana, Wossen et al. (2017) find self-coping mechanisms to initially be successful, but in the long-term insufficient and inadequate in mitigating household impacts. Ethiopia is a drought-prone country, with variation in frequency and severity by region (Kourouma et al., 2022). While coping strategies can initially minimize the negative impacts of climate variability, adaptation strategies that build resilience and can address the complexities in climate shocks are required in the long-term. Our results also indicate short-term exposure to temperature increases in the dry season were harmful, but long-term exposures were beneficial. Long-term exposures to temperature anomalies provide opportunities for adjustments and increased adaptation and resilience to climate variability. Climate adaptation measures examined by Mekonnen et al. (2021) in Southern Ethiopia include: soil and water conservation, the use of improved crop varieties, livestock diversification, growing short maturing varieties, changing planting and harvesting dates, income source diversification, reducing livestock, and irrigation. These adaptation measures can be used to increase resilience to long-term climate shocks, whereas coping strategies are most beneficial for short-term exposures.

Overall, more rainfall in the wet seasons favored food security, while precipitation during the dry season was disadvantageous to food security. These results can be contextualized alongside other relevant studies that investigate changes in temperature and precipitation patterns. Chou et al. (2013) find vertical moisture advection and evaporation positively correlated to increasing precipitation patterns in the wet seasons, whereas positive changes to evaporation and negative vertical moisture advection in the dry season create variability in drying trends. Additional climate models have suggested wet season increases in extreme precipitation and rainfall irregularity, along with summer warming events (Choi et al., 2022; Nikulin et al., 2018; Osima et al., 2018). With projected increases in climate variability, we can correspondingly expect household food security status to be impacted – and thus vulnerability and resilience.

Not only is food insecurity largely dependent on independent climate variables – it is also mitigated by household-level and demographic characteristics. Female-headed households were more

vulnerable to food insecurity and less resilient than male-headed households, consistent with previous findings indicating female-headed households are more sensitive to declines in precipitation events (Randell et al., 2022). Additionally, Teklewold et al. (2019) find gender disaggregation in household nutritional outcomes due to household characteristics in Ethiopia. Nutritional outcomes are vulnerable to existing gender inequalities, which can impede access to resources. Azong and Kelso (2021) findings indicate women within patrilineal systems of governance are more vulnerable to climate change than those within the matrilineal system – due to a lack of ability to exercise rights in the same way, thus making female-headed households more vulnerable to climate variability.

Similarly, our results found households composed of young children and elderly individuals to be more vulnerable and less resilient to food insecurities. This could potentially hint at less labor income or inability to contribute to agricultural productivity. These findings support expansive studies indicating marginalized groups are most vulnerable to climate shocks and food insecurity (Conway & Schipper, 2011; Admassie & Abebaw, 2014; Mueller & Gray, 2018; Mersha & van Laerhoven, 2018; Thiede et al., 2021; Tenzing & Conway, 2022). Additionally, we find age and education of the household head to have significant influence on protecting against food insecurity. Consistent with our results, Berhanu and Beyene (2015) find older household heads more likely to lack required labor power for land cultivation, or adamant about traditional farming practices like dry tilling. Higher education levels and lower age groups of the household head saw better food security status. Past reports have found maternal education and education levels of the household head to be a significant factor impacting resilience to climate stressors (Randell & Gray, 2016; Davenport et al., 2017; Nicholas et al., 2021; Thiede et al., 2021).

In addition to directly impacting food security outcomes, climate indirectly impacts food security through influences on income. Because crops are dependent on specific zonal conditions, changes in climate can have differential effects on agricultural production. In Kiremt, increases in rainfall positively impacted crop yields, namely wheat, teff, and barley, while increases in temperature led to higher off-farm activity. This corresponds to results indicating exposures to higher temperatures in Kiremt are beneficial to household food security, as greater rainfall was also linked to higher agricultural yields.



Higher temperatures in Kiremt alternatively resulted in off-farm income generating activities, which suggests effects to agricultural productivity. Increases in rainfall during Belg also resulted in higher wheat and barley yields, while increases in temperature hindered teff and sorghum production – resulting in declines in crop income. We didn't find significant associations between increased precipitation in Belg and greater food security outcomes, which could indicate a restraint on yield increases due to declined health conditions or inadequate infrastructures like road conditions. However, we did find higher temperatures in Belg were significantly associated with more months of inadequate food and a lower household dietary diversity score. Findings from Zhu et al. (2022) indicate overall global reductions to cropping frequency, caloric production, and crop caloric yield linked to warming, while increases in cropping frequency, caloric production, and crop caloric yield are linked to precipitation levels until a threshold is reached. Our results support this in that increases in temperature during the wet seasons resulted in higher non-farm income and declined crop income. This signifies farmers are looking elsewhere to supplement farm activity in response to impacted crop yields by climate variability. Therefore, while farmers are vulnerable to climate change due to impacts to agricultural production, those with alternative and supplemental livelihoods are more resilient to climate stressors.

Additionally, socio-economic factors played a role in contributing to the vulnerability of a household to food insecurity. Having greater access to farmland and improved roof structures indicate relationships to possible financial access that could shield households from food insecurity. Our findings indicate a link between less farmland owned and lowered food security outcomes, signifying conditions of vulnerability for households with less farm access. Access to land continues to remain a significant barrier to resilience, moderated by inadequate access to financial resources, time constraints, physical ability, land availability, etc. (Sanga et al., 2021). Further, improvements in roof material indicate physical conditions of housing quality, and therefore socio-economic status (Arias & De Vos, 1996). Our results suggest roof improvements are correlated to food security outcomes, with all five measures significantly improved, demonstrating substantial reductions in vulnerability and increases in resilience. We expected rural households dependent on agriculture to be particularly vulnerable to food shocks, but

we found no significant relationship between rural/urban status and changes to food security. We also expected a relationship between climate variability and child anthropometric outcomes, but found no significant relationship.

Given the degree of vulnerability linked to climate variability, dependent on socio-economic and demographic factors, steps to mitigate exposure to stressors and promote resilience among households should be prioritized. Barriers to land access and financial resources for rural populations continue to pose threats to climate adaptation and must be supported by increased investments and policies that promote financial equity and land justice. Ethiopia is specifically vulnerable to shifts in climate historical increases in rainfall and temperature trends have been identified (Gebrechorkos et al., 2019; Choi et al., 2022). Because variability in precipitation, temperature, and accompanying drought events will continue to shift plant physiology and harvesting time frames, increased investments in irrigational technologies are likely to improve agricultural production and therefore resilience to climate stressors. Implementation of irrigational technologies will largely be contingent on local infrastructures, water demand, and access to resources. Multi-cropping practices can similarly combat climate variability through increases to agricultural yield. Finally, greater emphasis on alternative supplementary livelihoods through access to education and training can contribute to household resilience in the face of climate stressors.

## REFERENCES

- Admassie, A., Abebaw, D., 2014. Rural Poverty and Marginalization in Ethiopia: A Review of Development Interventions BT - Marginality: Addressing the Nexus of Poverty, Exclusion and Ecology. Springer, Netherlands, Dordrecht, pp. 269–300.
- Asfaw, S., & Maggio, G. (2018). Gender, Weather Shocks and Welfare: Evidence from Malawi. *The Journal of Development Studies*, 54(2), 271–291.
- Aurino, E., Schott, W., Behrman, J. R., & Penny, M. (2019). Nutritional Status from 1 to 15 Years and Adolescent Learning for Boys and Girls in Ethiopia, India, Peru, and Vietnam. *Population Research and Policy Review*, 38(6), 899–931.
- Azong, M. N., & Kelso, C. J. (2021). Gender, ethnicity and vulnerability to climate change: The case of matrilineal and patrilineal societies in Bamenda Highlands Region, Cameroon. *Global Environmental Change*, 67, 102241.
- Baker, R. E., & Anttila-Hughes, J. (2020). Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa. *Scientific Reports*, 10(1), 18796.
- Barrett, C. B. (2010). Measuring Food Insecurity. *Science*, 327(5967), 825–828.
- Baye, K., and Hirvonen, K. (2020). Accelerating progress in improving diets and nutrition in Ethiopia. ESSP Working Paper 144. Washington, DC: International Food Policy Research Institute (IFPRI).
- Belachew, A., Tewabe, T. Under-five anemia and its associated factors with dietary diversity, food security, stunted, and deworming in Ethiopia: systematic review and meta-analysis. *Syst Rev* 9, 31 (2020).
- Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, 8(1), 123–138.
- Berhanu, W., & Beyene, F. (2015). Climate Variability and Household Adaptation Strategies in Southern Ethiopia. *Sustainability*, 7(6), 6353–6375.
- Bertelli, O. (2019). Food security measures in Sub-Saharan Africa. A Validation of the LSMS-ISA Scale. *Journal of African Economies*, 1–31.
- Bezabih, M., Di Falco, S., 2012. Rainfall variability and food crop portfolio choice: evidence from Ethiopia. *Food Security* 4 (4), 557–567.
- Brown, M. E., Funk, C., Pedreros, D., Korecha, D., Lemma, M., Rowland, J., ... & Verdin, J. (2017). A climate trend analysis of Ethiopia: examining subseasonal climate impacts on crops and pasture conditions. *Climatic Change*, 142(1), 169-182.
- Bohle, H. G., Downing, T. E., & Watts, M. J. (1994). Climate change and social vulnerability. *Global Environmental Change*, 4(1), 37–48.

- Calzadilla, A., Rehdanz, K., Betts, R., Falloon, P., Wiltshire, A., & Tol, R. S. J. (2013). Climate change impacts on global agriculture. *Climatic Change*, 120(1–2), 357–374.
- Call, M., & C. Gray. (2020). Climate anomalies, land degradation and rural out-migration in Uganda. *Population and Environment*, doi: 10.1007/s11111-020-00349-3
- Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., Ramirez-Villegas, J., Rosenstock, T., Sebastian, L., Thornton, P. K., & Wollenberg, E. (2016). Reducing risks to food security from climate change. *Global Food Security*, 11, 34–43.
- Carpena, F. (2019). How do droughts impact household food consumption and nutritional intake? A study of rural India. *World Development*, 122, 349–369.
- Choi, Y.-W., Campbell, D. J., & Eltahir, E. A. B. (2022). Near-term regional climate change in East Africa. *Climate Dynamics*.
- Chou, C., Chiang, J. C. H., Lan, C.-W., Chung, C.-H., Liao, Y.-C., & Lee, C.-J. (2013). Increase in the range between wet and dry season precipitation. *Nature Geoscience*, 6(4), 263–267.
- Conway, D., & Schipper, E. L. F. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *Global Environmental Change*, 21(1), 227–237.
- d’Errico, M., Romano, D., & Pietrelli, R. (2018). Household resilience to food insecurity: evidence from Tanzania and Uganda. *Food Security*, 10(4), 1033–1054.
- Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia. *American Journal of Agricultural Economics*, 93(3), 829–846.
- Dimitrova, A. (2021). Seasonal droughts and the risk of childhood undernutrition in Ethiopia. *World Development*, 141, 105417.
- United Nations, OCHA. Humanitarian Response Plan Ethiopia. Humanitarian Programme Cycle. February 2023.
- FEWS Network. Ethiopia Food Security Outlook June 2022 – January 2023. August 2022. Distributed by Famine Early Warning Systems Network.
- FAO, 2011. Ethiopia Country Programming Framework. Addis Ababa.
- FAO. 2016. AQUASTAT Country Profile – Ethiopia. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy
- FAO and WFP. 2023. Monitoring food security in food crisis countries and territories with conflict situations. A joint FAO/WFP update for the members of the United Nations Security Council, April 2023. Issue no. 12. Rome.
- FAO, IFAD, UNICEF, WFP and WHO. 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO.

- FAO, IFAD, UNICEF, WFP and WHO. 2022. The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable. Rome, FAO.
- Food Consumption Analysis. 2018. World Food Programme, Vulnerability Analysis and Mapping Branch (ODAV) (v1). Rome, Italy.
- Gebremariam, G., & Tesfaye, W. (2018). The heterogeneous effect of shocks on agricultural innovations adoption: Microeconometric evidence from rural Ethiopia. *Food Policy*, 74, 154-161.
- Gebrechorkos, S. H., Hülsmann, S., & Bernhofer, C. (2019). Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania. *International Journal of Climatology*, 39(1), 18–30.
- Gifford, R. M. (1995). Whole plant respiration and photosynthesis of wheat under increased CO<sub>2</sub> concentration and temperature: long-term vs. short-term distinctions for modelling. *Global Change Biology*, 1(6), 385-396.
- Gray, C., D. Hopping, and V. Mueller. (2020). The changing climate-migration relationship in China, 1989-2011. *Climatic Change* 160:103-122.
- Gray, C., and E. Wise. (2016). Country-specific effects of climate variability on human migration. *Climatic Change* 135(3): 555-568
- Hamza, I. A., & Iyela, A. (2012). Land use pattern, climate change, and its implication for food security in Ethiopia: A review. *Ethiopian Journal of Environmental Studies and Management*, 5(1), 26-31.
- Hirvonen, K., Wolle, A., Laillou, A., Vinci, V., Chitekwe, S., & Baye, K. (2021). Child growth faltering dynamics in food insecure districts in rural Ethiopia. *Maternal & Child Nutrition*.
- Hoddinott, John and Yisehac Yohannes. (2002) Dietary Diversity as a Household Food Security Indicator. Washington, D.C.: Food and Nutrition Technical Assistance Project, FHI 360.
- Jiren, T. S., Bergsten, A., Dorresteyn, I., Collier, N. F., Leventon, J., & Fischer, J. (2018). Integrating food security and biodiversity governance: A multi-level social network analysis in Ethiopia. *Land Use Policy*, 78, 420–429.
- Jones, A. D., Ngunjiri, F. M., Pelto, G., & Young, S. L. (2013). What are we assessing when we measure food security? A compendium and review of current metrics. *Advances in Nutrition*, 4(5), 481–505.
- Kassegn, A., & Endris, E. (2021). Review on livelihood diversification and food security situations in Ethiopia. *Cogent Food & Agriculture*, 7(1), 1882135.
- Kennedy, G., Berardo, A., Papavero, C., Horjus, P., Ballard, T., Dop, M., Delbaere, J., & Brouwer, I. D. (2010). Proxy measures of household food consumption for food security assessment and surveillance: Comparison of the household dietary diversity and food consumption scores. *Public Health Nutrition*, 13(12), 2010–2018.
- Konda, Issa, Ronaldo Sigauque, and Pascal Payet. (2008). “Guidance: How to Measure the Number of Months of Adequate Household Food Provisioning (MAHFP) Based on Quantitative Methods and Isolating Food Aid Provisions.” *Africare Food Security Review* 17.

- Kotir, J. H. (2011). Climate change and variability in Sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, 13(3), 587–605.
- Kourouma, J. M., Eze, E., Kelem, G., Negash, E., Phiri, D., Vinya, R., Girma, A., & Zenebe, A. (2022). Spatiotemporal climate variability and meteorological drought characterization in Ethiopia. *Geomatics, Natural Hazards and Risk*, 13(1), 2049–2085.
- Kristjansson, P., Neufeldt, H., Gassner, A. et al. Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa. *Food Sec.* 4, 381–397 (2012).
- Lovon, M., & Mathiassen, A. (2014). Are the World Food Programme’s food consumption groups a good proxy for energy deficiency? *Food Security*, 6(4), 461–470.
- Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability*, 13(3), 1318.
- Maxwell D, Caldwell R. (2008). *Coping Strategies Index: Field methods manual*, 2nd ed. Boston, MA: Tufts University.
- Maxwell, D., Vaitla, B., & Coates, J. (2014). How do indicators of household food insecurity measure up? An empirical comparison from Ethiopia. *Food Policy*, 47, 107–116.
- Maxwell, D., Ahiadeke, C., Levin, C., Armar-Klemesu, M., Zakariah, S., & Lamptey, G. M. (1999). Alternative food-security indicators: Revisiting the frequency and severity of ‘coping strategies’. *Food Policy*, 24(4), 411–429.
- Mekonnen, D. A., & Gerber, N. (2017). Aspirations and food security in rural Ethiopia. *FoodSecurity*, 9(2), 371–385.
- Mersha, A.A., van Laerhoven, F., 2018. The interplay between planned and autonomous adaptation in response to climate change: Insights from rural Ethiopia. *World Dev.*
- Mulwa, C. K., & Visser, M. (2020). Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Development*, 129, 104906.
- Mueller, V., and C. Gray. (2018). Heat and adult health in China. *Population and Environment* 40(1): 21–46.
- Nicholas, K., Campbell, L., Paul, E., Skeltis, G., Wang, W., & Gray, C. (2021). Climate anomalies and childhood growth in Peru. *Population and Environment*.
- Nikulin G, Lennard C, Dosio A et al (2018) The effects of 1.5 and 2 degrees of global warming on Africa in the CORDEX ensemble. *Environ Res Lett* 13(6):065003
- Niles, M. T., Emery, B. F., Wiltshire, S., Brown, M. E., Fisher, B., & Ricketts, T. H. (2021). Climate impacts associated with reduced diet diversity in children across nineteen countries. *Environmental Research Letters*, 16(1), 015010.
- Ofori, S. A., Cobbina, S. J., & Obiri, S. (2021). Climate Change, Land, Water, and Food Security: Perspectives From Sub-Saharan Africa. *Frontiers in Sustainable Food Systems*, 5, 680924.

- Osima S, Indasi VS, Zaroug M et al (2018) Projected climate over the Greater Horn of Africa under 1.5 C and 2 C global warming. *Environ Res Lett* 13(6):065004
- Pironon, S., Etherington, T. R., Borrell, J. S., Kühn, N., Macias-Fauria, M., Ondo, I., Tovar, C., Wilkin, P., & Willis, K. J. (2019). Potential adaptive strategies for 29 sub-Saharan crops under future climate change. *Nature Climate Change*, 9(10), 758–763.
- Randell, H., & C. Gray. (2016). Climate variability and educational attainment: Evidence from rural Ethiopia. *Global Environmental Change* 41: 111–123
- Randell, H., & C. Gray. (2019). Climate change and educational attainment in the global tropics. *Proceedings of the National Academy of Sciences* 116 (18): 8840-8845
- Randell, H., Jiang, C., Liang, X. Z., Murtugudde, R., & Sapkota, A. (2021). Food insecurity and compound environmental shocks in Nepal: Implications for a changing climate. *World Development*, 145, 105511.
- Sanga, U., Sidibé, A., & Olabisi, L. S. (2021). Dynamic pathways of barriers and opportunities for food security and climate adaptation in Southern Mali. *World Development*, 148, 105663.
- Seo, S. N., Mendelsohn, R., Dinar, A., & Hassan, R. (2009). A RICARDIAN ANALYSIS OF THE DISTRIBUTION OF CLIMATE CHANGE IMPACTS ON AGRICULTURE ACROSS AGRO-ECOLOGICAL ZONES IN AFRICA.
- Smith, L. C., & Frankenberger, T. R. (2018). Does resilience capacity reduce the negative impact of shocks on household food security? Evidence from the 2014 floods in Northern Bangladesh. *World Development*, 102, 358–376.
- Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Godfray, H. C. J., Gollin, D., Rayner, M., Ballon, P., & Scarborough, P. (2016). Global and regional health effects of future food production under climate change: A modelling study. *The Lancet*, 387(10031), 1937–1946.
- Swindale, Anne, and Paula Bilinsky. (2006). Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide (v.2). Washington, D.C.: FHI 360/FANTA.
- Tankari, M. R. (2020). Rainfall variability and farm households' food insecurity in Burkina Faso: nonfarm activities as a coping strategy. *Food Security*, 1–12.
- Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). Climate smart agricultural practices and gender differentiated nutrition outcome: An empirical evidence from Ethiopia. *World Development*, 122, 38–53.
- Thiede, B. C., Randell, H., & Gray, C. (2022). The Childhood Origins of Climate-Induced Mobility and Immobility. *Population and Development Review*, 48(3), 767-793.
- USAID. 2016. El Niño in Ethiopia, A Real-Time Review of Impacts and Responses 2015-2016.
- Vrieling, A., De Beurs, K. M., & Brown, M. E. (2011). Variability of African farming systems from phenological analysis of NDVI time series. *Climatic Change*, 109(3–4), 455–477.

- Waha, K., van Wijk, M. T., Fritz, S., See, L., Thornton, P. K., Wichern, J., & Herrero, M. (2018). Agricultural diversification as an important strategy for achieving food security in Africa. *Global Change Biology*, 24(8), 3390–3400.
- Wang, X. et al. (2020). Emergent constraint on crop yield response to warmer temperature from field experiments. *Nat. Sustain.* 3, 908–916.
- Wheeler, T., & von Braun, J. (2013). Climate Change Impacts on Global Food Security. *Science*, 341(6145), 508–513.
- Wiesmann, D., Bassett, L., Benson, T., & Hoddinott, J. (2009). Validation of the World Food Programme's Food Consumption Score and Alternative Indicators of Household Food Security.
- World Food Programme. (2007). Food consumption analysis: Calculation and use of the Food Consumption Score in food. World Food Programme Rome.
- World Food Programme. (2009). Comprehensive food security & vulnerability analysis. Guidelines. World Food Programme Rome.
- Wossen, T., Berger, T., Haile, M. G., & Troost, C. (2018). Impacts of climate variability and food price volatility on household income and food security of farm households in East and West Africa. *Agricultural Systems*, 163, 7–15.
- Zhu, P., Burney, J., Chang, J., Jin, Z., Mueller, N. D., Xin, Q., Xu, J., Yu, L., Makowski, D., & Ciais, P. (2022). Warming reduces global agricultural production by decreasing cropping frequency and yields. *Nature Climate Change*.