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From farm to market: Impacts of climate shocks on selected agricultural value chains in Ethiopia

Eleni Yitbarek¹, Wondimagegn Tesfaye²

Abstract

While many of the studies to date have focused on the production end of the value chain-i.e., ways to help farmers grow more food, there is limited evidence regarding the impacts of climate shocks on the other stages of agricultural value chains. Recognizing that food security is not just an issue of production, there is now an emerging literature that attempts to link climate change with agricultural value chains. This study fills a critical gap in the literature by assessing the impacts of weather shocks not only on production but also on the post-production stages (storage and sales) across the agricultural value chains of four key commodities in Ethiopia: teff, maize, coffee, and dairy. The study addresses two questions: (i) How do weather shocks impact different stages of agricultural value chains? and (ii) are the negative effects of weather shocks on agricultural value chains heterogeneous by gender? We document that negative rainfall shocks drastically reduce maize and teff yields by about 40% and 37%, respectively, and significantly impact teff storage. Coffee yield is less affected by rainfall shocks, though its storage decreases by 28%. Temperature increases reduce yields for maize, teff, and coffee, with coffee also experiencing declines in storage and sales. For teff, temperature increases reduce the quantity stored by about 6.7% and sales by 18.5%. Similarly, an increase in temperature lowers coffee sales by 24.6%. Dairy production shows minimal sensitivity to both rainfall shocks and temperature variations. These effects vary by gender of the household head. For maize, temperature increases negatively affect yields more for male-headed households. Teff and coffee show varying impacts based on gender, with male-headed households experiencing more pronounced negative effects.

Keywords: climate shocks, value chains, agriculture, Ethiopia *JEL classification: Q12, Q54, Q18, Q13, J16*

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1. Introduction

Africa's agricultural production faces numerous challenges, including climate change impacts, making it difficult to meet the rising demand for food, raw materials for industry, and foreign exchange (Omotoso et al., 2023; FAO, 2019; Hisano et al., 2018). Weather conditions and atmospheric changes have a significant impact on agricultural productivity (Baudoin et al., 2018; Dakurah, 2021; Ado et al., 2019), especially in Sub-Saharan Africa, where climate is the primary factor of production and modern technology adoption is limited (Mihiretu et al., 2020; Makuvaru et al., 2020). Climate change affects the food production system in several ways, ranging from reduced productivity to its indirect effects, such as fluctuations in food prices and market supply (Ado et al., 2019). Numerous studies have documented climate change's impact on Africa's agriculture production. However, the impact of climate change on other parts of the agricultural value chain, including harvesting, storage, processing, and marketing stages, is often neglected (Rosenstock et al., 2019). This stands in sharp contrast to the emerging body of research that recognizes that food security is not just an issue of production but also distribution, access, and affordability (Dazé & Dekens, 2016; Hochachka, 2023; Tchonkouang et al, 2024). The lack of focus on post-production stages neglects critical links in the food system, which are essential for food security and market stability. Understanding how climate shocks impact other stages of the value chain-such as storage, processing, and marketing is crucial for designing effective resilience strategies.

This study investigates how exposure to weather (rainfall) shocks, defined as the negative deviation of annual rainfall from the long-term average, affects the different stages of maize, teff, coffee, and dairy value chain using data from Ethiopia. We also included temperature as a separate variable to capture additional aspects of weather variability. Examining the different stages of the agricultural value chain, from production to market, enables us to assess how climate shocks affect not only yields but also storage and sales, thus providing a more comprehensive understanding of the vulnerabilities throughout the chain. Extreme weather is causing significant problems for smallholder farmers and others who depend on agricultural value chains in developing countries. Climate-related shocks can significantly impact macro variables such as GDP and agricultural exports (Akyapi et al., 2022; Jones, 2010). On a micro level, climate shocks are highly correlated and have significant effects on the different phases of agri-food value chain functions such as production (Stevanović et al., 2016; Haverkort and Verhagen, 2008), storage (Agrawal et al., 2023), and retail marketing and final product sales (James & James, 2010), especially in developing countries. Climate resilience across the entire value chain is critical, as these interconnected stages influence the ability to respond to climate shocks and maintain food security. Climate change will drive responses and adaptations throughout agrifood systems. Changes in growing conditions for many crops will alter agricultural production patterns. Along with these shifts in crop production, rising temperatures, changes in humidity levels, and increased extreme weather will also affect the value chains through which agricultural products are traded, aggregated, processed, and sold to consumers (de Brauw & Pacillo, 2022). As climate changes, agrifood value chains must adapt to new cropping patterns and changes in investment and input needs. The global response to climate change has also created challenges for low- and middleincome countries. While high-income countries are taking steps to reduce their carbon emissions, less developed economies that depend on carbon-intensive global value chains will need to adapt quickly. A recent study demonstrates that countries more deeply integrated into GVCs recovered more quickly than others during a crisis, and diversification brings about resilience (Brenton et al.,

2022). Therefore, developing countries should seek new opportunities and integrate into GVCs that support a low-carbon future. Governments in developing countries must safeguard against the risk of increasing food and nutrition insecurity, and agrifood value chains must be transformed to address climate security concerns. This transformation must strengthen the resilience of all stages of agricultural value chains, including production, storage, processing, and marketing.

Climate change impacts all actors in agricultural value chains, but in different ways and to different degrees. In response, policymakers need to focus on ways to reduce food loss and waste in value chains to yield more food from their agrifood systems and potentially alleviate the local environmental stress associated with the development of food systems in the short term. In the medium term, there is a need for investments in climate-smart infrastructure to support the development of food chains. Such investments are crucial for enabling the post-production stages of agricultural value chains to adapt to climate variability and maintain food security. If investments in agricultural value chain development are to have a sustainable impact in reducing poverty and increasing food security, climate resilience must be a priority outcome. To achieve this, all actors along the chain must be aware of climate risks and empowered to manage these risks. This ultimately needs building climate-resilient value chains (Dazé & Dekens, 2016).

The study investigates how the impact of weather shocks varies across selected economically important commodities in Ethiopia, namely maize, teff, coffee, and dairy and at different stages of the value chain- production, storage, and marketing. By focusing on how each stage of the value chain is affected by weather shocks, this research provides policymakers and stakeholders with a clearer understanding of where vulnerabilities lie and how interventions can be targeted to strengthen the different stages in the chain. We utilize data from the Ethiopian Socioeconomic Panel Survey (ESPS) conducted in 2018/19 and 2021/22. The ESPS includes geographic information about households, which allows the combination of survey data with weather information, particularly historical temperature and precipitation data to generate weather shock indicators. The analytical method exploits the panel nature of the data and the random and exogenous nature of the weather shock variables to analyze the impacts of weather shocks on different stages of the value chain of the selected commodities.

This research contributes to the literature in two main ways. Firstly, it fills a gap in the existing literature by examining the impacts of weather shocks on post-production stages, which have received limited attention so far. In this regard, the study will contribute to the emerging but scant literature that links climate and weather shocks with economic outcomes such as poverty, income, food security, and nutrition (Michler et al., 2019; Mujeyi et al., 2021; Ngoma, 2018; Teklewold et al., 2013; Tesfaye et al., 2020). The study also considers the gender dimension of climate shocks. From a policy perspective, investigating the impacts of climate shocks on different stages of the value chain will help design effective food security-enhancing strategies. Second, looking at the impact on market participation would provide relevant evidence since market participation is often associated with an increase in rural incomes and poverty reduction in agriculture-based economies. Overall, the results will provide evidence that could help identify adaptation interventions to support climate-smart value chains at the different stages of the agricultural value chain and promote the consideration of mainstreaming climate change into developmental planning.

Our research provides valuable insights into the impact of short-term extreme weather events and long-term weather characteristics on the production and post-production outcomes of maize, teff, coffee, and dairy value chains. Our results reveal the differential impacts of rainfall and

temperature shocks on the yield, storage, and sales of maize, teff, coffee, and dairy products. Rainfall shocks notably reduce maize and teff yields, with teff also experiencing significant declines in storage, highlighting its sensitivity to rainfall variability. Conversely, coffee yields are less affected by rainfall shocks, though storage is diminished, likely due to humidity issues. Temperature increases reduce teff storage and sales, while coffee sales also decline. Dairy production is resilient to rainfall and temperature shocks, though prolonged rainfall deficits could eventually impact feed availability. Temperature increases adversely affect yields across maize, teff, and coffee, with coffee also experiencing declines in storage and sales. Overall results underscore that while some crops can adapt to climatic extremes, others remain highly vulnerable, necessitating targeted adaptation strategies to enhance resilience throughout the agricultural value chain. The effects of weather shocks vary by gender of the household head. Rainfall shocks do not have significant gender-specific effects on maize, but temperature increases negatively impact maize yields more for male-headed households. This suggests that larger-scale operations managed by men are more vulnerable. For teff and coffee, temperature changes and rainfall shocks also show varying impacts based on gender. Male-headed households experience more pronounced negative effects, while female-headed households benefit from increased rainfall in milk production.

The rest of this paper is structured as follows: Section 2 lays the conceptual framework based on the empirical literature. Section 3 presents the data and descriptive statistics for the variables of interest. Section 4 discusses the estimation strategy. Section 5 discusses the econometric results. Section 6 concludes the study and points out some policy implications of the findings.

2. Conceptual framework

Drawing on the existing literature, we develop a simplified conceptual framework by considering two elements: (i) the value chain approach and (ii) impacts on value chains. The ideal approach for a value chain analysis is to follow a value chain approach that encompasses all the actors, activities, and outcomes involved in the agricultural value chain. This includes agricultural production, storage, processing, distribution, and consumption. However, our data does not allow us to do so. Our approach, although not pragmatic, is to analyze the impacts of weather shocks on different stages of the value chain – production, storage, and market participation using farmers as the only actors in the system. The weather shocks under consideration in this study include rainfall shocks, temperature increases, and erratic rainfall patterns. Rainfall shock is the standardized deviation of total rainfall from its long-term normal. A negative rainfall shock, or drought, occurs when annual or seasonal rainfall is below the long-term average by at least 0.5 or 1 standard deviation. Additionally, we construct a continuous precipitation-based drought index, which quantifies the intensity of drought events (see section 3.1 for a detailed discussion). These weather shocks are expected to affect various stages of the agricultural value chain differently, from crop production to storage and market participation.

Weather shocks in the form of droughts, increased temperatures, or erratic rainfall patterns could have significant impacts on maize, teff, coffee, and dairy value chains in three main ways: (i) gradual changes, (ii) increased likelihood of shocks, and (iii) increased potential for conflict. While crop production is most obviously affected by climate change, risks of postharvest losses will increase, and incentives for finance and insurance providers will also change. Threats to livelihoods and food security increase the risk of civil strife and conflict, which can disrupt whole

value chains. Consumers may add to the pressures for change across entire value chains not only through changes in diets but also through demand for sustainably produced products. All these changes have implications for value chain actors, from smallholders to urban consumers (de Brauw & Pacillo, 2022). Climate shocks not only affect the agricultural aspects of the value chains but also have broader socio-economic implications. They can lead to increased food prices, reduced income for farmers, and potential disruptions in the supply chain. Weather shocks could affect the different stages of the agricultural value chains in different ways depending on crop type and household typology.

Production: At the input and production stage, it would alter households' planting decisions, which are a function of (historical) temperature and precipitation patterns. Land productivity is significantly lower in areas exposed to higher impacts of weather shocks. Weather shocks would also make farmers risk averse (as they face an increased risk of exposure to price volatility etc.), over and beyond their effect on land productivity. High exposure to climate shocks discourages smallholder farmers from investing in high-risk, high-return technologies, such as inorganic fertilizers, further depressing productivity (Kebede, 2022). Risk-averse households also allocate a significant share of their land to low-value crops such as staples since climate shocks lead to food shortages and food price risks that further put pressure on motives for subsistence production. Vogel et al. (2019) analyzed the effects of climate extremes such as droughts and heatwaves on maize, soybeans, rice, and spring wheat yield anomalies, using yield data and machine-learning algorithms. Climate extremes explained a significant portion of yield anomalies, with temperaturerelated extremes having a stronger association with yield anomalies than precipitation-related factors. Climate conditions in their models explained varying percentages of yield anomalies; 49% for maize, 46% for spring wheat, 28% for rice yield, and 20% for soybeans. Knox et al. (2012) conducted a systematic review and meta-analysis of projected climate change impacts on crop productivity in Africa and South Asia. Their study reported a mean yield decline of 8% by the 2050s for major crops, with significant regional variations. Across Africa, mean yield changes of -17% (wheat), -5% (maize), -15% (sorghum) and -10% (millet) and across South Asia of -16% (maize) and -11% (sorghum) were estimated. These findings stress the need for regionspecific adaptive strategies to mitigate the adverse effects of climate change on food security.

Harvesting and storage: Climate change leads to the outbreak of pests and diseases that affect harvest and storage decisions. This is coupled with a lack of improved harvesting and storage technologies. In this regard, climate shocks are likely to reduce the amount of crop stored, thereby reducing the benefits producers would get from price arbitrage. Climate shocks can also influence the prices of agricultural commodities. Studies have shown that weather shocks, such as rainfall shortages, significantly impact grain prices in Ethiopia (Hill & Fuje 2020). For example, the price of maize and teff can increase in response to drought conditions, as the reduced supply leads to higher demand and prices (Dorosh et al, 2020). These price increases can have implications for food security and affordability for consumers. Climate shocks (at high latitudes) significantly impact crops' storage process and post-harvest quality, like potatoes, due to increased susceptibility to bacterial infection (Haverkort & Harris, 1987; Haverkort & Verhagen, 2008). These challenges will increase as climate shocks become more frequent (Dazé & Dekens, 2016).

Value addition and Marketing: Climate shocks would also make farmers risk averse (as they face an increased risk of exposure to price volatility etc.) with additional pressure on meeting food subsistence needs. Low surplus availability further limits market participation due to low

productivity and post-harvest losses. Lower land productivity resulting from exposure to climate shocks would reduce surplus availability. Risk-averse households accumulate large food storage reserves before marketing their surplus. Post-harvest losses could also reduce the amount of surplus available for marketing. While overall value addition in Ethiopia is low, a lack of adequate infrastructure coupled with climate shocks deters value addition (Bekabil, 2014). As a result, most producers could sell unprocessed products. By reducing the opportunity to benefit from value addition, climate shocks are likely to reduce rural incomes. Climate shocks impact retail, packaging, and distribution processes, introducing variability that affects product integrity and supply chain efficiency. Variations in climatic conditions during product distribution, especially extremes in temperature and humidity, adversely affect the mechanical properties of packaging materials like paperboard. James & James (2010) examined the effect of climate change on the cold chain for food safety and quality. The findings suggest that rising temperatures may result in increased energy usage for refrigeration, which could impact the cost and sustainability of food distribution networks. Borocz et al. (2015) studied the distribution environment in less-thantruckload shipments between Central Europe and South Africa, emphasizing the importance of considering physical and climatic conditions during transportation. The study finds that understanding physical and climatic conditions, such as shocks, temperature, and humidity changes during transportation, is crucial for designing better packaging to protect products throughout the supply chain.

3. Data

The primary data source for this study are the 2018/19 Ethiopian Socioeconomic Panel Survey (ESPS) (referred to as 2019 ESPS for brevity) and the 2021/22 ESPS (referred to as 2021 ESPS for brevity). The ESPS is part of the Living Standards Measurement Study-Integrated Surveys in Agriculture (LSMS-ISA), a collaborative project of the World Bank and the Central Statistics Agency of Ethiopia. ESPS is a publicly available rich geo-referenced nationally representative household level data (at urban and rural levels). For this study, we used data from rural households. The survey provides rich information on household characteristics, income sources, household assets, consumption expenditure, shocks and coping strategies, and community-level data. ESPS has an agriculture module that captures detailed information on post-planting and post-harvest activities, including landholding, crop production and disposition, and livestock ownership.

ESPS also georeferenced households, which allows us to match the household survey data with geospatial climate information. Monthly data is sourced from CHIRPS dataset that combines satellite imagery, ground station observations, and meteorological data to generate high-resolution rainfall estimates. The spatial resolution of this data is 0.05 degrees (~5.3 km2) at pentadal, dekadal, and monthly temporal resolutions (Funk et al. 2014). For temperature analysis, gridded daily minimum and maximum temperature datasets are obtained from the NOAA Physical Sciences Laboratory, with a resolution of 0.5 degrees. Given the high spatial resolution of the data, household and weather datasets were merged at the enumeration area (EA) level. This is one of the few studies, along with Di Falco and Vieider (2022) and Mulungu et al (2024), to combine weather and household-level survey data at a high spatial resolution in a sub-Saharan African country. Although rainfall conditions during planting and growing seasons are the most critical to determining farmers' livelihoods, our main analysis used the annual rainfall and temperature values to capture the post-planting and postharvest periods that could affect household decisions

at different value chain stages. As discussed below, we test the sensitivity of our results to changing the weather (rainfall) shock indicators to the use of meher and belg season rainfall instead of annual rainfall.

3.1 Rainfall Shock

Our analysis captures rainfall shocks in two distinct ways. Firstly, we define a categorical variable for rainfall shocks, adopting the method of Bora (2022) and Yu and Babcock (2010). This variable, referred to as rainfall shock (S_r), is calculated as the standardized deviation of total rainfall from its long-term normal (the mean annual rainfall from 1981 to the relevant survey year for each enumeration area, EA). The long-term average calculated from the 1980s up to the year of the survey. The formula for S_r , expressed as total rainfall deviation (RD), is:

$$S_r = RD_{it} = \frac{(R_{it} - \bar{R}_i)}{\sigma(R)_i}$$

where R_{it} is the total rainfall (annual or relevant meher and belg season) for EA *i* in year *t*, \bar{R}_i is the long-term normal rainfall for EA *i*, and $\sigma(R)_i$ is the standard deviation of annual (belg and meher) rainfall for EA *i*. *RD* value less than zero signifies a negative rainfall shock. This approach aligns with the established literature on weather shocks (Amare et al. 2018; Rajeevan, Gadgil, and Bhate 2010, Mulungu et al. 2024), which adopts the conventional definition of rainfall anomalies as the standardised deviation of the annual or seasonal rainfall in household locality from the historical average for the same locality. For robustness checks, we further delineate rainfall shock at cutoff points of -0.5 and -1 that suggest more severe rainfall shock. The rainfall anomaly is considered a negative rainfall shock or a drought event whenever the annual or seasonal rainfall falls short of the long-term average by a standard deviation of 0.5 or 1 (Amare et al., 2018; Azzarri & Signorelli, 2020; Kevin et al., 2024).

Secondly, we construct a continuous precipitation-based measure for negative rainfall shocks, termed the drought index, quantifying drought intensity. This index is derived by isolating the negative shock years from the RD as:

$$D_{it} = \{-\min(0, RD_{it})\}$$

This continuous measure is consistent with the drought indices used in Auffhammer *et al.* (2012) and Amare *et al.* (2018) studies. Our approach of using standardised rainfall deviations and the drought index is motivated by several reasons specific to our study's context. First, rainfall is the country's most direct driver of agricultural production (Bouteska et al., 2024), and we aim to quantify the effect of deviations in rainfall from long-term norms, which directly impact crop yields, storage, and market participation. The use of standardized rainfall deviations and a drought index is a method that has been widely applied in similar agricultural settings (Amare et al., 2018; Rajeevan et al., 2010). Second, while composite indexes such as SPEI integrate precipitation and evapotranspiration, the inclusion of evapotranspiration may not always add value in contexts where agricultural productivity is predominantly governed by rainfall patterns (as is the case in the context of our study). For example, the interplay between temperature and precipitation in determining agricultural outcomes in our study area may be less relevant compared to other regions where water availability from evapotranspiration (due to higher temperatures) plays a more

significant role. Thus, SPEI's additional complexity, while informative in some contexts, may be less suitable for our specific research area, where rainfall deviations are the primary driver of agricultural shocks. Finally, our methodology benefits from the simplicity of relying on readily available precipitation data over extended periods (e.g., 1981 to 2021). In countries like Ethiopia, the availability of high-quality, long-term evapotranspiration data required to calculate SPEI accurately is often limited or inconsistent (Dinku, 2019). On the other hand, rainfall data is more reliable and available at the required granularity for Ethiopia, ensuring the robustness and reliability of our analysis, without introducing potential bias or measurement errors from incomplete evapotranspiration data. While primarily focusing on precipitation, our study acknowledges the limitations highlighted by (Fontes et al., 2020) regarding the exclusion of temperature in defining drought. To address this, we included temperature as a separate variable to capture additional aspects of weather variability. Table 1 provides summary statistics for the weather shocks and other control variables.

Variables	Mean	SD	Min	Max
Female headed	0.23	0.42	0	1
Age of household head	45.5	15.1	15	97
Adult equivalent	4.0	1.8	0.7	13.4
Share of members with primary education or above	0.10	0.19	0	1
Land size imputed (ha)	0.99	2.02	0	200
Household asset index (all assets)	-1.88	0.83	-3.37	6.27
Household possess mobile phone	0.47	0.50	0	1
Total livestock holdings, TLU	2.73	3.28	0	63.3
Local weekly village market	0.59	0.49	0	1
Improved crop storage	0.04	0.18	0	1
Irrigate scheme in the community	0.56	0.50	0	1
Any financial institution in the community	0.39	0.49	0	1
All weather road in the community	0.56	0.50	0	1
Household reached by extension services	0.39	0.49	0	1
Household reported market shock	0.36	0.48	0	1
Household uses improved maize seed	0.25	0.43	0	1
Household uses inorganic fertilizer for maize	0.29	0.45	0	1
Crop protection for stored maize	0.43	0.50	0	1
Household uses improved teff seed	0.03	0.18	0	1
Household uses inorganic fertilizer for teff	0.26	0.44	0	1
Crop protection for stored teff	0.39	0.49	0	1
Household uses improved coffee seed	0.01	0.11	0	1
Crop protection for stored coffee	0.14	0.35	0	1
Share of improved animals in total herd - Cows only	0.03	0.15	0	1
Self-reported drought shock	0.26	0.44	0	1
Temperature	19.7	3.0	13.8	29.5
Rainfall shock and drought:				

Table 1. Summary of main controls - household survey and weather variables

Rainfall shock (annual TRD < 0)	0.392	0.488	0	1
Drought intensity index (annual)	0.236	0.417	0	1.89
Rainfall shock (meher and belg TRD < 0)	0.371	0.483	0	1
Drought intensity index (meher and belg)	0.188	0.339	0	1.67

Source: Authors computation based on pooled ESS 2019 and 2022

3.2 Commodity focus

The objective of the study is to assess the impacts of weather change on each stage in the value chain: production, storage, processing, and marketing. However, due to data challenges related to processing or value addition (no information on the sale of processed commodities), the study focuses on the other three nodes of the value chain. While the best practice for a value chain analysis study is also to track the whole set of actors along the chain, this study focuses on farmers as key value chain actors as producers, marketers, and consumers due to data constraints. We focus on four commodities: cereal crops (teff and maize), one cash crop (coffee), and one type of livestock commodity (dairy). Teff and maize are the two major cereals cultivated in Ethiopia. Teff holds the largest acreage, followed by maize, sorghum, barley, wheat, millet, and rice (Dessie, 2018). Teff is a high-value crop with high urban demand. Coffee is also a major cash crop with high prospects for income for farmers as it has high local and global demand. Finally, livestock is the most important means of livelihood (food and income) for the country's pastoral (and agropastoral) communities. Most importantly, there is a recent shift in diets from staples to animalorigin commodities due to population growth, urbanization, and shifting consumption patterns (Herrero & Thornton, 2013), highlighting the paramount importance of livestock (commodities) in the broader food systems and agricultural value chains (Singh et al, 2013). A recent study that attempts to prioritize value chains in Ethiopia emphasizes that cereal value chains are among those whose expansion would be most effective at generating economic growth, reducing national and rural poverty, creating jobs, and diversifying diets (Benfica & Thurlow, 2019).

Figure 1 presents the share of households cultivating a crop of interest and producing dairy. The data show that maize is the crop cultivated by most households, followed by teff. The share of households cultivating maize increased from 48 percent in 2019 to 51 percent in 2022. However, there is no change in the share of households that cultivate teff (33 percent) and coffee (25 percent) over the survey period. The share of households engaged in dairy production is around 47 percent, with no change over the survey period.





Looking at production patterns in terms of total area planted and harvested (in hectares), our data show that rural households allocate more land to teff production than maize and coffee (Figure 2). Smallholder farmers' participation in teff production is influenced by age, land fertility, oxen ownership, family labor, and distance from extension services (Goshu, 2016). The crop significantly contributes to smallholders' food security and cash income (Belayneh et al., 2019). Our data further show that households harvest less area than the area they planted. This reflects pre-harvest crop damage, and that could be due to climate-related factors, among others. Regarding dairy production, the number of large ruminants milked remains unchanged at around 1.6, and the number of cows owned slightly increased from 1.1 in 2019 to 1.3 in 2022.









Source: Authors computation based on ESS 2019 and 2022

The post-harvest crop disposition pattern of households shows that maize storage is relatively more important than maize sale, while the opposite is true for coffee (Figure 3). The higher share of households that store maize than those that sell maize implies that households mainly use maize for consumption and are less likely to benefit from price arbitrage. The share of households selling maize increased from 3.6 percent in 2019 to 13 percent in 2022. Such an increase could imply either (i) rural households decided to sell staples to benefit from price arbitrage due to weather shocks induced increase in prices or (ii) drought shocks negatively affect production and force households to sell not because they have a surplus but to cope with the shock. The share of households that sell teff increased over time. Our data provides evidence that the share of households that sell teff has significantly increased between 2019 (27 percent) and 2022 (42 percent). This is consistent with the increase in demand for teff due to the nutrition transition happening in the country. There is also increase in the share of households that sold milk between 2018/19 (2.8 percent) and 2021/22 (7.4 percent). In Ethiopia, numerous factors influence dairy market participation and milk supply. Age, education, land ownership, and cooperative membership significantly impact market participation and access to cooperative milk markets (Gemeda et al, 2018; Kuma et al, 2013). Factors like market information access, price, and availability of animal feed influence milk supply volume (Dehinenet et al 2014). Overall, the observed results are consistent with the conventional wisdom that households are less likely to sell staple crops such as maize but are highly likely to sell high-value and cash crops such as teff and coffee.



Figure 3. Storage and market participation patterns by commodity

Source: Authors computation based on ESS 2019 and 2022

Table 2 provides the descriptive statistics for key agricultural variables. For maize, the average yield is 4,743 kg per hectare. The average quantity sold is 370 kg, and the average quantity stored is 174 kg. For teff, the average yield is 1,618 kg per hectare, while quantities sold and stored average 136 kg and 121 kg, respectively. Coffee yields average 14,475 kg per hectare, though quantities sold and stored are considerably lower, averaging 1,321 kg and 16 kg, respectively.

Dairy production averages 978 liters annually, with substantial variability indicated by the high standard deviation. The nominal value of milk sold averages 695 Birr, while gross earnings from milk products average 235 Birr. These statistics highlight the considerable range of production and market participation across different crops and dairy products.

	Mean	SD	Min	Max
Maize:				
Yield by area harvested (kg/ha)	4,136	10,922	0	96,612
Quantity sold (kg)	370	837	0.703	9,000
Quantity stored (kg)	174	749	0	15,000
Teff:				
Yield by area harvested (kg/ha)	920	1,043	0	9,733
Quantity sold of teff (kg)	136	145	1.65	3,500
Quantity stored (kg)	121	686	0	31,802
Coffee:				
Yield by area harvested (kg/ha)	13,435	52,728	0	408,342
Quantity sold of coffee (kg)	1,321	16,800	0.001	322,500
Quantity stored (kg)	16	161	0	6,000
Dairy:				
Total quantity of milk per year (liters)	537	992	0	8,760
Nominal Value of milk sold (Birr)	695	5,615	0	217,920
Earnings from milk products sold (Nominal) (Birr)	235	1,813	0	90,720

Table 2. Summary statistics of the main outcome variables

Source: Authors computation based on pooled ESS 2019 and 2022

4. Empirical strategy

The effect of weather shocks on different value chains is analyzed using selected outcome indicators for each commodity of interest—maize, teff, coffee, and dairy—at the different stages of the value chains: (i) yield at the production stage, (ii) storage at harvesting/storage, (iii) and market participation or quantity of production sold at the marketing stage. The following panel data model is estimated to establish the relationship between weather shocks and the outcomes of interest:

$$y_{it} = \alpha_i + \beta S_{it} + \gamma X_{it} + \epsilon_{it}$$

where y_{it} is the outcome of interest and S_{it} is the weather shock indicator. The weather shock variables are chosen based on recent works that utilize panel data models to establish the link between weather shocks and economic outcomes (Azzarri & Signorelli, 2020; Blanc & Schlenker, 2017). In addition to the weather shock variables, we control for other variables (X_{it}) including household head characteristics (gender, age, education), household characteristics (e.g., family size, access to credit, access to private and/or social transfers), wealth (land holding, livestock holding, asset index), and access to services (markets, roads, extension).

The relationship in the above equation is estimated using pooled OLS regression with region-year fixed effects and a conditional (recursive) mixed process estimator with multilevel random effects and coefficients (Roodman, 2011). The conditional (recursive) mixed process estimator allows the simultaneous modeling of the effects of weather shocks on different outcomes, which are supposed to be related to each other in a recursive manner. The use of the panel data regression is inspired by the fact that assessments of weather change impacts on agriculture increasingly rely on panel models to examine the relationship between agricultural outcomes and weather fluctuations. Panel models are especially preferred since they account for the fact that locations across space differ not only in their weather but also in many other variables (e.g., soil quality) that might be correlated with climate (Blanc & Schlenker, 2017). We also test how the impact of weather shocks differs across male and female-headed households.

5. Econometric Results

This section presents the results of various econometric models used to evaluate the effects of weather shocks on specific value chains and different stages within each value chain.

5.1.Effect of rainfall shocks and temperature

Table 3 reports the estimated effects of rainfall shock and temperature on the yield, storage, and sales of maize, teff, coffee, and dairy products. The results reveal the differential impact of rainfall shocks and temperature on various agricultural outputs. A negative rainfall shock— annual rainfall is 1 SD below the long-term average —reduces maize yield by approximately 39.7 percent compared to a positive rainfall shock.³ The substantial reduction in maize yield due to negative rainfall shocks underscores maize's high dependency on water. Maize is an annual crop that requires consistent rainfall, particularly during its critical growth stages. A shortfall in expected rainfall can lead to inadequate soil moisture, which is essential for seed germination, plant growth, and grain development, resulting in a significant yield drop. Negative rainfall shock also has a significant and negative effect on teff production; a negative rainfall shock (a 1 SD decrease in annual rainfall relative to the long-term average) leads to a 37.3% reduction in teff yield. Teff's negative response to rainfall shocks can be attributed to its growth in often arid and semi-arid environments where consistent rainfall is crucial. A negative rainfall shock can disrupt the delicate balance of soil moisture needed for teff, affecting its entire growth cycle from germination to harvest, thereby reducing production. We do not find any significant change in coffee and milk yields due to negative rainfall shock. The resilience of coffee yield in the face of negative rainfall shocks may be due to the perennial nature of coffee plants. Moreover, coffee plants can sometimes benefit from mild stress conditions, which can enhance the concentration of flavors in coffee cherries. However, this is contingent on the specific environmental context and the timing of the stress. The lack of significant impact on milk yield suggests that dairy production has adaptive mechanisms to cope with short-term rainfall variability. Livestock can often maintain production using stored feeds or relying on irrigated pastures. However, it is important to note that severe or extended rainfall deficits could eventually have detrimental effects on dairy production if they lead to long-term feed scarcity or affect the health and nutrition of the animals. The results underscore

³ Since the dependent variable is log-transformed, we calculate the change in the dependent variable for a 1 unit change in the independent variable of interest as $100 \times [\exp^{\beta} -1]$.

the significant correlation between rainfall anomalies and cereal production, with insignificant effects for perennials and livestock.

Table 3. Estimated effects of rainfall shock and temperature: conditional mixed process estimates

Panel A. Maize

	Yield	Quantity	Quantity
	(kg/ha)	stored (kg)	sold (kg)
Rainfall shock	-0.397**	-0.064	-0.113
	(0.174)	(0.137)	(0.225)
Temperature	-0.123***	-0.006	-0.051
	(0.034)	(0.027)	(0.036)
Controls	Yes	Yes	Yes
N	2,183	301	1,963

Panel B. Teff

	Yield	Quantity	Quantity
	(kg/ha)	stored (kg)	sold (kg)
Rainfall shock	-0.373**	-0.598***	0.142
	(0.184)	(0.165)	(0.121)
Temperature	-0.110***	-0.067**	-0.185***
	(0.037)	(0.030)	(0.033)
Controls	Yes	Yes	Yes
Ν	1,062	314	1,007

Panel C. Coffee

	Yield	Quantity	Quantity
	(kg/ha)	stored (kg)	sold (kg)
Rainfall shock	-0.217	-0.280*	-0.248
	(0.302)	(0.165)	(0.250)
Temperature	-0.109*	0.031	-0.246***
	(0.066)	(0.028)	(0.046)
Controls	Yes	Yes	Yes
Ν	1,006	423	858

Panel D. Dairy (milk)

	Quantity per year (liters)	Value of milk sold (Birr)	Earnings from milk products sold (Birr)
Rainfall shock	-0.049	-0.468	-0.770*
	(0.236)	(0.386)	(0.395)
Temperature	-0.039	0.019	-0.048
	(0.055)	(0.077)	(0.080)
Controls	Yes	Yes	Yes
Ν	250	322	322

Note: 0.01 - ***; 0.05 - **; 0.1 - *. Standard errors clustered at the household level. The analysis identifies rainfall shock using deviations of annual rainfall from the long-term average (1981 to survey year) rainfall. The other shocks identified are using information on mean annual temperature. Control variables include region and year fixed effects, as well as demographic (gender of head, age of head, adult equivalent, education of members), wealth (land holding, livestock holding, mobile ownership, asset index), service access (presence of a local market, community crop storage, irrigation scheme, financial institution, and all-weather road in the community, extension service) and market shocks controls included but not reported. Additional crop or commodity-specific controls such as improved seeds, fertilizer, protection of stored crops (maize, teff, and coffee), and improved cow herds (dairy) are included in the regressions. Yield of crops is calculated by the area harvested. All outcome variables are in logs.

Regarding the effects of temperature, a 1-degree Celsius increase in temperature leads to a significant decrease in the yield of maize, teff, and coffee, with maize yield dropping by 12.3 percent and teff and coffee yields by approximately 11 percent. The negative effect on maize yield could be because maize is sensitive to temperature, particularly during key growth stages. Maize is particularly sensitive to temperature increases during key growth stages. High temperatures can cause heat stress, which accelerates crop development, shortens the grain-filling period, and reduces kernel size and number, leading to lower yields. Teff is resilient but vulnerable to high temperatures, which can shorten its growth period and seed production capacity. Even slight temperature increases beyond the optimal range can negatively affect yields in environments where teff is grown. Coffee plants have a higher threshold for heat stress due to their perennial nature and deeper root systems. However, prolonged high temperatures can still impact bean development, resulting in smaller beans and reduced yields. Livestock, such as dairy cows, may show minimal direct effects from temperature variations on milk yield because they can adapt through measures like shade and water supplementation. However, high temperatures can indirectly affect milk production by reducing pasture quality and water availability. The results suggest that temperature variations play a key role in cereal production with minimal effects on perennial crop production and livestock. This could be due to the indirect effect on milk yield through affecting pasture. These findings highlight the need for crop-specific and livestockspecific adaptation strategies to mitigate the risks associated with temperature extremes, such as developing heat-tolerant varieties, optimizing irrigation, and implementing livestock heat stress management practices.

The analysis of weather shocks on post-production outcomes such as storage and sales reveals nuanced effects that vary by crop and stage of the value chain. Negative rainfall shock is found to have no significant effect on maize storage and sales. The lack of significant impact from negative

rainfall shocks on maize storage and sales could be because maize, once harvested, is relatively robust to short-term weather variations. Storage facilities for maize might be designed to withstand such shocks, or it could be that maize is quickly sold or consumed after harvest, reducing the exposure to weather-related risks during the storage phase. A negative rainfall shock is associated with a decrease in the quantity stored of teff by 59.8%. This suggests that rainfall shocks not only reduce the yield of teff but also significantly reduce the amount that is stored. The significant decrease in teff storage due to negative rainfall shocks suggests that teff, unlike maize, may be more susceptible to post-harvest losses due to weather conditions. Teff grains are smaller and may require more careful storage conditions to prevent spoilage. In regions where teff is a staple, the infrastructure for storage might not be as resilient to rainfall variability, leading to greater losses. Rainfall shock can negatively impact the storage of coffee, leading to a decrease in coffee storage of 28 percent, although the effect on yield and quantity sold is not statistically significant. The decrease in coffee storage due to rainfall shock could be attributed to the sensitivity of coffee beans to humidity and temperature. Increased humidity from rainfall shocks can promote mold growth and spoilage, particularly if the storage facilities are not equipped to control these conditions. The lack of significant effects on yield and quantity sold might be due to the ability of coffee plants to withstand short-term rainfall variations, as mentioned earlier, or due to the timing of the shocks relative to the coffee production cycle. The marginal significance of rainfall shocks on earnings from milk products, with a 77% decrease, could be due to several factors. Rainfall shocks might disrupt the supply chain, making it challenging to transport milk to markets, or they could affect the feed quality and availability for dairy cattle, indirectly impacting milk production and, thus, earnings. The effects on quantity per year and value of milk sold are not statistically significant.

Temperatures do not significantly affect maize storage and sales, indicating their importance in the production stage. The analysis shows that an increase in temperature is associated with a decrease in the quantity of teff stored and sold, as well as the quantity of coffee sold. An increase in temperature decreases the quantity stored of teff by 6.7% and the quantity sold by 18.5%. This is consistent with the understanding that temperature can affect crop growth and storage conditions. A 1-unit-increase in temperatures is associated with a 24.6% decrease in the quantity sold of coffee. This is in line with research indicating that coffee is sensitive to temperature changes, which can affect both the quality and quantity of the harvest. The decrease in the quantity of teff stored and sold, as well as the quantity of coffee sold, in response to temperature increases, aligns with the understanding that high temperatures can affect not only crop growth but also storage conditions. High temperatures can lead to increased pest activity and spoilage rates, which would affect the amount of crop available for storage and sale. The results highlight that temperature variability is an important determinant of crop storage and market participation, depending on the crop of interest. However, we do not find any effect of temperature changes on dairy production, marketing, and earnings. The absence of significant temperature effects on dairy production, marketing, and earnings could be because dairy cattle are often managed in controlled environments where temperature extremes can be mitigated, or because the dairy sector has developed effective strategies to cope with temperature variability.

The results consistently demonstrate that climatic extremes, such as rainfall shocks and temperature fluctuations, negatively affect agricultural yields, storage, and sales for crops and dairy products, with certain effects being statistically significant. Weather variations are particularly correlated with reduced production and market participation for staple crops like maize and cash crops like teff, as evidenced by the negative temperature coefficients in their respective production, storage, and sales equations. Notably, negative rainfall shocks—extreme weather

events characterized by significant deviations from average annual rainfall—have a substantial adverse effect on the post-production stages of high-value crops, including teff and coffee. This observation may indicate a growing resilience to drought among Ethiopian households, possibly due to the widespread adoption of drought-resistant crop varieties and improved farming practices, similar to trends in other Sub-Saharan African countries. These insights highlight the necessity of examining the entire agricultural value chain when assessing the impact of climate variability. While some crops and stages exhibit resilience, others remain highly vulnerable, calling for targeted interventions to bolster storage conditions, market access, and overall climate resilience. Furthermore, the findings emphasize the importance of crop and livestock types in assessing the vulnerability of agricultural systems to climate shocks and underscore the need for tailored adaptation strategies to mitigate sector-specific risks and maintain food security and agricultural productivity in the face of a changing climate.

5.2.Effects of drought

Our investigation has previously focused on the effects of rainfall shocks, which are categorized into discrete classes. We now extend our analysis to consider the impact of drought intensity as a continuous variable, which allows for a more granular assessment of its influence on agricultural outcomes. The salient points from the results, as detailed in Table 4, are as follows: Firstly, there is a notable decline in maize and teff yields with increasing drought intensity, with an increase in drought intensity. In contrast, coffee yields respond positively to an increase in drought intensity, which is an unexpected finding and suggests an area for further investigation. Secondly, the quantity of maize stored is marginally affected, while teff and coffee storage quantities decrease with rising drought intensity. The quantity of teff sold also diminishes, whereas the quantity of coffee sold exhibits a paradoxical increase, again indicating a need for additional analysis. In the dairy sector, drought intensity does not significantly impact milk yield, marketing, or earnings. In summary, the results underscore that drought shocks have a significant and variable impact on cereal yields and the post-harvest processes of high-value crops such as teff and coffee.⁴

	Yield	Quantity	Quantity
	(kg/ha)	stored (kg)	sold (kg)
Maize	-0.638**	-0.397*	-0.290
	(0.304)	(0.204)	(0.267)
Teff	-1.303***	-1.155***	-0.404**
	(0.360)	(0.302)	(0.201)
Coffee	0.956***	-0.637***	0.621***
	(0.362)	(0.175)	(0.236)

Table 4. Estimated impacts of drought intensity on outcomes: conditional mixed process estimates

⁴ Table A1 in the Annex reports the impact of self-reported drought shocks. We noted that self-reported drought significantly reduces teff production. Households reported to be affected by drought also report lower amounts of stored teff and decreased sales of teff and coffee. Additionally, drought shocks result in reduced milk yields.

	Total quantity of	Value of milk sold	Earnings from
	milk per year	(Birr)	milk products sold
	(liters)		(Birr)
Dairy	-0.572	0.326	0.403
	(0.377)	(0.528)	(0.551)

Note: 0.01 - ***; 0.05 - **; 0.1 - *. Standard errors clustered at household level. Separate regressions are run for each commodity with temperature, region and year fixed effects, as well as socio-demographic and geographic controls included (not reported). The analysis identifies drought intensity by recoding positive deviations in rainfall from long-term mean normal into zero and negative deviations into positive to create a continuous index. The yield of crops is calculated by the area harvested.

5.3. Sensitivity to different thresholds

Our analysis extends to examining the sensitivity of our core results presented in Table 3 to the use of alternative thresholds for defining rainfall shocks. These thresholds are based on deviations from the long-term mean, with the literature-reviewed cutoffs discussed in section 3.1 serving as our reference points. Specifically, we redefine rainfall shocks using deviations of -0.5 and -1 standard deviations from the mean as alternative cutoffs. The reclassified outcomes are displayed in Table 5, with columns 1-3 detailing the results for the -0.5 standard deviation cutoff and columns 4-6 for the -1 standard deviation cutoff. This exercise reinforces our initial findings regarding the negative consequences of rainfall shocks on agricultural outputs. Our discussion focuses explicitly on the ramifications of rainfall shocks as determined by these cutoffs.

The analysis delineates that rainfall shocks do not significantly impact maize yield, storage, and sales when applying a -0.5 standard deviation (SD) threshold. However, shifting to a more severe -1 SD threshold, the impact on maize yield remains statistically negligible, but the quantity sold is notably affected, denoting a marked reduction in maize sales. For teff, the yield is consistently and significantly diminished across both cutoffs, and the quantity sold is negatively affected, with significant coefficients regardless of the threshold applied. In the case of coffee, a -0.5 SD cutoff reveals a detrimental effect on yield, though the results across different measures are not uniformly consistent; the only significant outcome is a reduction in the quantity stored. Conversely, the quantity sold exhibits a positive and significant coefficient. As for dairy products, the impact of rainfall shock on most outcomes is statistically inconsequential at the -0.5 SD threshold, except the value of milk sold, which shows a positive and significant correlation, indicating an increase in sales value under such climatic conditions. When the threshold is intensified to -1 SD, the total annual quantity of milk displays a negative and significant coefficient, suggesting a decline in milk production in response to more severe rainfall shocks. The table elucidates that the operational definition of rainfall shock, predicated on deviations from the long-term average, exerts differential effects on agricultural and dairy outputs. The severity of rainfall shock (-0.5 SD versus -1.0 SD) alters both the significance and the magnitude of these effects, underscoring the critical nature of shock severity in evaluating the impacts of climate variability on agricultural outcomes.

Panei A. Maize	Т	RD < -0.5 SE)	TR	D < -1.0 SD	
	(1)	(2)	(3)	(4)	(5)	(6)
	Yield (kg/ha)	Quantity stored (kg)	Quantity sold (kg)	Yield (kg/ha)	Quantity stored (kg)	Quantit y sold (kg)
Rainfall shock	-0.094	-0.049	0.016	-0.206	-0.071	- 0.685* *
	(0.248)	(0.191)	(0.212)	(0.358)	(0.238)	(0.298)
Temperature	-0.131***	-0.008	-0.054	-0.132***	-0.008	- 0.076* *
	(0.035)	(0.027)	(0.037)	(0.034)	(0.028)	(0.036)
Controls N	Yes 2.183	Yes 301	Yes 1.963	Yes 2,183	Yes 301	Yes 1.963
Panel B. Teff	_,100	001	1,5 00		0.01	1,5 00
	Т	RD < -0.5 SI)	TRD < -1.0 SD		
	(1) Yield (kg/ha)	(2) Quantity stored (kg)	(3) Quantity sold (kg)	(4) Yield (kg/ha)	(5) Quantity stored (kg)	(6) Quantit y sold (kg)
Rainfall shock	-0.355*	0.196	0.580***	-1.303***	0.086	- 0.647* *
	(0.186)	(0.127)	(0.163)	(0.464)	(0.420)	(0.295)
Temperature	-0.098***	-0.181***	-0.060**	-0.115***	-0.087***	- 0.181* **
	(0.037)	(0.034)	(0.030)	(0.037)	(0.029)	(0.031)
Controls N	Yes 1,062	Yes 314	Yes 1,007	Yes 1,062	Yes 314	Yes 1,007
Panel C. Coffee	T	RD < -0.5 SI)	TR	D < -1.0 SD	
	(1) Yield	(2) Quantity	(3) Quantity	(4) Yield	(5) Quantity	(6) Quantit

Table 5. Sensitivity of results to rainfall deviation cutoffs to define rainfall shock

	(kg/ha)	stored (kg)	sold (kg)	(kg/ha)	stored (kg)	y sold
		(8/				(kg)
Rainfall shock	1.122***	-0.547***	0.644**	0.284	-0.338**	-0.041
	(0.399)	(0.177)	(0.270)	(0.421)	(0.171)	(0.317)
Temperature	-0.103	0.034	- 0.226***	-0.106	0.035	- 0.242* **
	(0.065)	(0.027)	(0.045)	(0.066)	(0.028)	(0.048)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
N	1,006	423	858	1,006	423	858

Panel D. Dairy (milk)

	TRD < -0.5 SD			TRD < -1.0 SD		
	(1) Yield (kg/ha)	(2) Quantity stored (kg)	(3) Quantity sold (kg)	(4) Yield (kg/ha)	(5) Quantity stored (kg)	(6) Quantit y sold (kg)
Rainfall shock	-0.477	0.987*	0.480	-0.957**	0.608	-0.822
	(0.413)	(0.571)	(0.489)	(0.407)	(0.644)	(0.855)
Temperature	-0.038 (0.054)	0.024 (0.075)	-0.066 (0.082)	-0.060 (0.052)	0.040 (0.079)	-0.075 (0.083)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Ν	250	322	322	250	322	322

Note: 0.01 - ***; 0.05 - **; 0.1 - *. Standard errors are clustered at household level. The analysis identifies shocks using negative deviations of belg and meher rainfall from its historical average. Region and year-fixed effects, as well as socio-demographic and geographic controls, were included but not reported. Crop yield is calculated by area harvested.

5.4. Sensitivity to seasonal rainfall changes

Our study expands to assess whether our main findings presented in Table 3 are affected by alternative definitions of rainfall shocks based on seasonal rainfall during the belg and meher seasons rather than annual rainfall figures. Considering the pivotal role of the belg and meher seasons in the country's agricultural calendar, rainfall during these periods may be a more critical determinant of crop yields and other related outcomes. Our sensitivity analysis thus utilizes negative rainfall shocks during these specific seasons. Table 6 presents pooled Ordinary Least Squares (OLS) regression results, which scrutinize the impact of these seasonally defined rainfall shocks on agricultural and dairy sector outcomes. The results are systematically arranged into

panels for maize, teff, coffee, and dairy (milk), with the dependent variables including yield, quantity stored, and quantity sold for crops, as well as the total annual quantity of milk, the value of milk sold, and earnings from milk products sold for dairy. This analysis concentrates on the effects of rainfall shocks during the belg and meher seasons.

Negative rainfall shocks-deviations from the long-term average-have been observed to negatively and significantly affect the quantity of maize sold. In contrast, neither yield nor quantity stored are significantly impacted. This finding holds when employing a -0.5 standard deviation (SD) cutoff. However, an unexpected significant increase in the quantity of maize sold arises with a severe rainfall shock at a -1 SD cutoff. The findings indicate that farmers may increase maize sales after a shock from the previous season's harvest, taking advantage of higher prices due to scarcity.. For teff, a negative deviation from the long-term mean rainfall consistently exerts a significant negative effect on both yield and quantity sold, with the impact on quantity sold is particularly significant at the -0.5 SD cutoff. Negative rainfall shocks during the meher and belg seasons are linked to a significant decrease in the quantity of coffee stored and sold. When a more severe shock at a -0.5 SD cutoff is considered, the effect on quantity sold remains significant, but there is no significant effect on yield and quantity stored. In the dairy sector, any negative deviation from the long-term mean rainfall correlates with a significant decrease in earnings from milk products sold. Yet, the total quantity of milk per year and the value of milk sold are not significantly affected. The results are consistent at a -0.5 SD cutoff, indicating that a more severe rainfall shock significantly affects the value of milk sold.

The findings show that unexpected changes in rainfall have varying effects on the agricultural and dairy sectors. Significant adverse effects are observed on the quantity of maize and teff sold, as well as on the value of milk sold and earnings from milk products in the dairy industry. Conversely, the impacts on yield and quantity stored exhibit less consistency, indicating variable responses to climatic shocks. These findings emphasize the vulnerability of agricultural outcomes to climate variability and the necessity of incorporating different levels of shock severity into impact assessments.

Panel A. Maize	е													
		TRD < 0 SD		T	RD < -0.5	SD	TRD < -1.0 SD				Drought intensity			
	(1) Yield	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)		(10)	(11) ((12)
	(kg/ha)	Quantit y stored (kg)	Quantit y sold (kg)	Yield (kg/ha)	Quanti ty stored (kg)	Quantit y sold (kg)	Yield (kg/ha)	Quan tity store d (kg)	Quan ty sold (kg)	iti Y (k	ield g/ha)	Qua tity stor d (kg	in Qu y solv e	antity d (kg)
Rainfall shock	-0.016	0.084	0.313** *	0.115	-0.033	0.541** *	0.566	- 0.061	1.029)* -().013	0.01	-0.4	459**
	(0.144)	(0.190)	(0.106)	(0.246)	(0.180)	(0.166)	(0.490)	(0.29 1)	(0.30	6) (0	.300)	(0.2 2)	3 (0	.200)
Temperatur e	- 0.128** *	-0.045	-0.005	- 0.126* **	-0.044	-0.018	- 0.124** *	0.045	0.00	4 0.	- 129* **	- 0.04	-0	0.013
	(0.034)	(0.036)	(0.027)	(0.035)	(0.036)	(0.028)	(0.034)	(0.03 7)	(0.02	7) (0	.034)	(0.0 6)	3 (0	.028)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	s T	Yes
N Duru al D. Taff	2,183	301	1,963	2,183	301	1,963	2,183	301	1,96	3 2	,183	301	l I	,963
Рапеі Б. Тејј	TRD < 0 SD		TRD < -0.5 SD		5 SD	TRD < -1.0 SD			Drou		ught intensity			
	(1) Yield	(2)	(3)	(4)	(5)	(6)	(7)	(8))	(9)	(1	10)	(11)	(12)
	(kg/ha)	Quantit y stored	t Quant ity sold	Yield (kg/ha)	Quanti stored (kg)	ty Quanti ! y sold	it Yield (kg/ha)) Quan) y store	ntit (ed	Quanti y sold	t Yi (kg	eld g/ha)	Quantit y stored	Quanti ty sold

Table 6. Estimated effects of meher and belg rainfall shock: Pooled OLS results

		(kg)	(kg)			(kg)		(kg)	(kg)		(kg)	(kg)
Rainfall shock	-0.336**	0.157	- 0.721* **	0.053	-0.166	- 1.029** *	-0.560	-0.290	-0.075	-0.357	0.127	- 0.829* **
	(0.161)	(0.121)	(0.142)	(0.220)	(0.160)	(0.224)	(0.597)	(0.210)	(0.540)	(0.295)	(0.193)	(0.297)
Temperatur e	-0.101***	- 0.173** *	- 0.063* *	- 0.108** *	- 0.164***	-0.057*	- 0.105** *	- 0.168** *	- 0.080** *	- 0.101* **	- 0.172** *	- 0.065* *
	(0.037)	(0.033)	(0.030)	(0.037)	(0.033)	(0.030)	(0.037)	(0.034)	(0.030)	(0.038)	(0.033)	(0.030)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1,062	314	1,007	1,062	314	1,007	1,062	314	1,007	1,062	314	1,007
Panel C. Coff	ee TF	RD < 0 SD		1	FRD < -0.5 \$	SD	T	RD < -1.0	SD	Dr	ought inte	ensity
	(1) Yield	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	(kg/ha)	Quantit y stored (kg)	Quantit y sold (kg)	Yield (kg/ha)	Quantity stored (kg)	Quantit y sold (kg)	Yield (kg/ha)	Quantit y stored (kg)	Quantit y sold (kg)	Yield (kg/ha)	Quantit y stored (kg)	Quantit y sold (kg)
Rainfall shock	-0.155	0.520**	0.356**	0.385	-0.362	- 0.685** *	1.267	1.484**	-0.569*	0.403	0.054	- 0.679** *
	(0.279)	(0.245)	(0.136)	(0.344)	(0.289)	(0.155)	(0.810)	(0.349)	(0.337)	(0.433	(0.304)	(0.206)

-0.078

-0.166** 0.025

-0.088

- 0.226**

0.003

0.011

-0.253***

Temperatu

re

-0.117*

0.019

-0.264** -0.095

		*						*			*	
	(0.068)	(0.048)	(0.029)	(0.067)	(0.049)	(0.028)	(0.069)	(0.049)	(0.029)	(0.068	(0.053)	(0.031)
	· · · ·	· · · ·	× ,		× /		× /	× ,	× ,)	× ,	· · · ·
Controls	Yes	Yes	Yes	Yes								
Ν	1,006	423	858	1,006	423	858	1,006	423	858	1,006	423	858

Panel D. Dairy (milk)

	TRD < 0 SD			TRD < -0.5 SD			TRD < -1.0 SD			Drought intensity		
	(1) Yield (kg/ha)	(2) Quantit	(3) Quant	(4) Yield	(5) Quantity	(6) Quantit	(7) Yield	(8) Quantit	(9) Quantit	(10) Yield	(11) Quantit	(12) Quantity
		y stored (kg)	ity sold (kg)	(kg/ha)	stored (kg)	y sold (kg)	(kg/ha)	y stored (kg)	y sold (kg)	(kg/ha)	y stored (kg)	sold (kg)
Rainfall shock	-0.172	-0.180	- 0.843* *	-0.365	-1.032**	0.403	0.018	-0.674	0.476	-0.245	- 1.013* *	0.019
	(0.252)	(0.387)	(0.338	(0.232)	(0.438)	(0.592)	(0.363)	(0.558)	(0.997)	(0.308)	(0.505)	(0.641)
Temperatu re	-0.046	0.003	-0.060	-0.054	-0.020	-0.050	-0.044	-0.003	-0.055	-0.049	-0.009	-0.059
	(0.055)	(0.080)	(0.085	(0.055)	(0.082)	(0.086)	(0.055)	(0.081)	(0.085)	(0.054	(0.081)	(0.086)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ν	250	322	322	250	322	322	250	322	322	250	322	322

Note: 0.01 - ***; 0.05 - **; 0.1 - *. Standard errors clustered at household level. Region and year fixed effects as well as socio-demographic and geographic controls included but not reported. The analysis identifies rainfall shocks as negative deviations of meher and belg rainfall from its historical average. The other shocks identified are using information on rainfall (historical average) and mean annual temperature. Yield of crops is calculated by area harvested.

5.5.Heterogenous effects by gender

Previous assessments of climate impacts on agriculture have underscored the differential effects on men and women, which are attributable to their distinct social roles, responsibilities, and resource endowments (FAO, 2024; Wossen, 2016).⁵ This exercise aids us in segmenting our analysis by gender. We focus solely on the effects of negative rainfall shocks (annual rainfall 1 standard deviation below the long-term average) and temperature variations, replicating our main results in Table 3 by the gender of the household head. Figure 4 plots the heterogeneous effects obtained by running separate regressions for a sample of male—and female-headed households. Our split-sample analysis yields mixed results.

The findings suggest that rainfall shocks (annual rainfall 1 SD below the long-term average) and temperature variations have heterogeneous effects on production, storage, and market participation, contingent on the gender of the household head. While rainfall shocks do not induce gender-specific disparities in maize yield, storage, or sales, temperature increases correlate with a decrease in maize yields for male-headed households. The absence of gender-specific effects on maize in response to rainfall shocks may indicate that maize cultivation practices and the necessary resources are equally accessible and utilized by both male and female-headed households. However, the negative yield effects of temperature on male-headed households could be due to the larger scale of operations typically managed by men, which may be more vulnerable to temperature extremes, possibly because of factors such as crop type and the timing of agricultural activities. Regarding teff, rainfall shocks have a negative effect on storage in male-headed households, without gender-specific effects on yield or sales. Temperature changes lead to decreased teff sales for male-headed households. The negative impact of rainfall shock on teff storage among maleheaded households, with no gendered effects on yield and sales, could suggest that men may have larger quantities of stored crops at risk during extreme weather conditions. The decrease in teff sales for male-headed households with temperature changes might reflect market dynamics where men are more involved in selling crops, and thus, their income is more directly affected by the reduced crop quality or quantity due to temperature stress. The same pattern holds for coffee. A similar pattern was observed for coffee, as for teff, suggesting that the crops managed by maleheaded households are more sensitive to climatic shocks, possibly due to the scale of production or the methods of cultivation and storage employed.

Contrarily, rainfall shock positively influences milk production in female-headed households, potentially due to sociocultural factors, as women predominantly oversee milk production and marketing. Rainfall shocks are also associated with reduced dairy product earnings in male-headed households. The positive effect of rainfall shock on milk yield among female-headed households could be related to the fact that increased rainfall may improve pasture quality and water availability, thus benefiting livestock health and milk production, which are often managed by women. Conversely, the decrease in earnings from dairy products among male-headed households might be due to the disruption of market access or increased costs associated with transporting goods during periods of excessive rainfall. Temperature changes seem to have no gender-specific impact on dairy production and marketing. The absence of gender-differentiated impacts from temperature changes on dairy production and marketing could indicate that the dairy sector has a

⁵ https://www.fao.org/climate-smart-agriculture-sourcebook/enabling-frameworks/module-c6-gender/chapter-c6-1/en/

certain resilience to temperature fluctuations, or that both male and female-headed households have adopted similar coping strategies to mitigate the effects of temperature changes.

Figure 4. Heterogenous effects by gender



a. Maize







Notes: Standard errors are clustered at the household level. All regressions include controls, region, year, and region-year-year fixed effects. All outcome variables are in logs.

Our gender-disaggregated results provide a more nuanced understanding of the complex interplay between gender, climate shocks, and agricultural outcomes. The results have several implications for gender, climate shocks, and value chains. First, gender-sensitive approaches are needed in agricultural policy and support programs due to the differential impacts on male and femaleheaded households. Secondly, understanding gender roles in agricultural practices is crucial for equitable resource allocation and access. Third, targeted risk management strategies are necessary for male-headed households vulnerable to temperature shocks in maize, teff, and coffee production. Interventions to stabilize markets or support alternative income-generating activities during climate shocks are important due to the influence of gender on market participation and income. Fourth, the dairy sector's resilience to temperature changes suggests that effective coping strategies could be replicated in other sectors to enhance climate resilience. Fifth, sociocultural dynamics must be considered in climate adaptation strategies to ensure alignment with existing gender roles and responsibilities. Overall, the findings underscore the need to integrate gender considerations into the development of resilient agricultural value chains to effectively support both men and women in the face of climate variability.

6. Conclusion

The study examines the effects of climate shocks on various nodes of the value chain for key commodities in Ethiopia: teff, maize, coffee, and dairy. The study utilizes nationally representative household panel survey data matched with weather data extracted from global databases. The survey data has detailed agriculture and household sections that allow the construction of outcome

indicators at different nodes of the agriculture value chain: production, storage, and marketing. The study focuses on the production, storage, and marketing of maize, teff, and coffee, as well as the production and marketing of dairy products. The extracted weather data allows the construction of various contemporaneous and long-term weather characteristics and rainfall shock and temperature indicators. The robustness of the results is also tested using self-reported drought shocks and different rainfall shocks using different thresholds and seasonal rainfall patterns.

Our findings reveal how rainfall and temperature shocks affect these agricultural products' yield, storage, and sales. Negative rainfall shocks, defined as annual rainfall 1 standard deviation below the long-term average, significantly reduce maize and teff yields. The results underscore the crops' high dependence on consistent rainfall. However, coffee and milk yields show resilience to such shocks, likely due to the perennial nature of coffee plants and adaptive mechanisms in dairy production. Temperature increases have a pronounced effect on the yields of maize, teff, and coffee, highlighting the sensitivity of these crops to heat stress. However, temperature changes do not significantly impact dairy production, suggesting effective adaptation strategies in the dairy sector. Post-production outcomes also exhibit nuanced effects, with negative rainfall shocks significantly reducing teff and coffee storage, while maize storage and sales remain unaffected. Temperature increases decrease the quantity of teff stored and sold, as well as the quantity of coffee sold, indicating the importance of temperature in crop storage and market participation.

Our findings demonstrate that climatic extremes negatively impact agricultural yields, storage, and sales, with significant effects on staple crops like maize and high-value crops like teff and coffee. These insights highlight the necessity of examining the entire agricultural value chain when assessing the impact of climate variability and underscore the need for targeted interventions to enhance resilience. Additionally, our analysis of drought intensity as a continuous variable reveals a notable decline in maize and teff yields with increasing drought intensity, while coffee yield responds positively, suggesting an area for further investigation. The results emphasize the importance of crop-specific and livestock-specific adaptation strategies to mitigate the risks associated with climatic extremes. Furthermore, our sensitivity analysis underscores the robustness of our core findings and highlights the critical role of seasonal rainfall in determining agricultural outcomes further underscore the importance of considering gender in climate impact assessments and developing targeted interventions to address specific vulnerabilities of male and female-headed households.

Given that rural households are vulnerable to current and future weather variability and shocks, there is a need to support these households in their path to development. In this regard, there is a need to strengthen coping strategies and facilitate policy interventions focusing on climate change adaptation and mitigation. Promoting the development of climate-smart agriculture practices that have yield-increasing and risk-reducing potential and postharvest management practices that help reduce harvest and storage loss are crucial. Relatedly, governments and stakeholders need to facilitate access to finance, information, and infrastructure in rural areas that could complement the climate change adaptation strategies rural households use. Such interventions could help improve the resilience capacity of vulnerable populations. While the finding of this study is important from a policy perspective, future studies could expand this work by using novel weather databases and integrating other value chain actors to provide a better picture of the weather shocks-agriculture value chains nexus.

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Appendix A

Table A1 assesses the stability of our findings against alternative indicators of weather shocks, focusing on drought shocks as self-reported by households. The results reveal that such drought shocks have a negative and statistically significant impact on teff production, even after adjusting for various observable household-level confounding factors. The influence of weather shocks further extends to post-harvest activities. Households affected by drought shocks report decreases in the quantity of teff stored and in the quantities of teff and coffee sold. Drought shocks also negatively impact milk yield. Collectively, the evidence suggests that households in hotter and drier regions tend to have lower maize, teff, and coffee yields, reducing surpluses for storage and sale. Nonetheless, the data indicates that weather shocks do not significantly impact dairy production and marketing processes.

	Yield (kg/ha)	Quantity sold (kg)	Quantity stored (kg)
Maize	-0.064	-0.025	0.061
	(0.265)	(0.229)	(0.166)
Teff	-0.640**	-0.801***	-0.654***
	(0.262)	(0.222)	(0.215)
Coffee	-0.221	-1.076***	-0.002
	(0.419)	(0.338)	(0.130)
	Milk yield	Value of milk	Earnings from
	(liters)	sold (Birr)	Milk products (Birr)
Dairy	-1.149**	0.860	-0.258
	(0.458)	(0.681)	(0.481)

Table A1. Impacts of drought shock: self-reported drought shocks

Note: 0.01 - ***; 0.05 - **; 0.1 - *. Standard errors clustered at household level.

All regressions include controls, region, year, and region-year year fixed effects.

All outcome variables are in logs. Self-reported shock is based on households' self-response related to drought experience.