# Exploring the Impact of Climate Smart Innovations on Household Food Security in Ethiopia

*Sisay Belay Bedeke*

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# Exploring the Impact of Climate Smart Innovations on Household Food Security in Ethiopia

*By*

*Sisay Belay Bedeke*
*Department of Rural Development and Economics,*
*Wolaita Sodo University* ss

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# Abstract

Agro-food systems in Sub-Saharan Africa are frequently hampered by climate change as most farmers rely heavily on a climate-sensitive rainfed system. To improve agricultural production and achieve food security while building resilience to climate risks, the promotion of Climate Smart Innovations (CSIs) such as crop choice and conservation tillage in combination with irrigation use is critically required. Although there is extensive literature in Ethiopia on the drivers of CSI adoption, there are mixed findings on the single and joint CSI adoption impacts on household food security. To this end, this study examines factors influencing a single and joint adoption of CSI and how this adoption impacts household food security in Ethiopia. Data on social, biophysical, and economic factors, institutional support systems, CSI adoption, and food security were obtained from a panel Ethiopian Socio-economic Survey (ESS) data, a nationally representative survey, covering three waves (2013/2014, 2015/2016, and 2018/2019). Descriptive statistics such as mean and percentages as well as an endogenous switching regression model were applied to estimate the effect of a single and joint CSI adoption on household food security while at the same time accounting for endogeneity problems. Findings indicate that a single and joint CSI adoption has positive effects on HFCS, but negative effects on the HFIAS and CCSI. Results reveal that a single CSI adoption has positive and significant gains over the joint CSI adoption in terms of HFCS. This is supported by the positive and significant gains for the single adoption of crop choice only and irrigation use only compared to the gains obtained from the joint adoption of crop choice, conservation tillage, and irrigation practices. Hence, the results do not support the notion that the joint adoption of large complementary CSI often results in higher gains in food security. Based on these results, it was concluded that improvement in food security is not only driven by the type and number of CSIs jointly adopted but rather depends on several policy-relevant variables including access to credit services and access to weather information, and membership status in farmer/women organizations. This suggests that greater support in terms of improving access to credit and weather information should be in place for CSI non-adopters to reduce food insecurity.

**Keywords**: Climate change risk, climate-smart innovation, agricultural productivity, food security, panel data, Ethiopia.

# 1. Introduction

## Background

Global climate change is posing an increasing threat to agro-food systems, particularly in Africa, highly reliant on rainfed systems (Gram et al., 2020). In Ethiopia, climate models indicate that the country will face significant changes in climate (Wassmann et al., 2019), which may intensify vulnerability to multiple shocks (Tesfaye et al., 2020). Average annual temperatures in Ethiopia increased by 1.3 °C, with an average rate of 0.28 °C over the past decades (Ali et al., 2022) whereas future temperatures are expected to rise by 1.7-2.2 °c in the mid-21st century (Etana et al., 2020). While the increase in temperature is significant, changes in precipitation are more ambiguous and are associated with substantial volatility and large spatiotemporal variability. Although the average precipitation in northern highland areas of Ethiopia showed increasing trends, in southern and south-eastern lowland areas the average rainfall is declining since the mid-20th century (WBG, 2020). While the inter-seasonal rainfall trends across Ethiopia are highly variable, dryland land areas will experience a significant reduction in rainfall. As a result, the length of the growing season (March-September) is expected to decline by about 15% (NCEA, 2015). Several nationwide drought events along with more localized drought events have occurred over the recent decades (Ali et al., 2022). Future increases in drought intensity are likely to result in substantial losses, jeopardizing agricultural systems (Etana et al., 2020; Kassa & Abdi, 2022).

As a result of climate change, Ethiopia is frequently facing severe food deficit and limited ability to procure adequate, healthy, and nutritious food leading to food insecurity (Ahmed et al., 2018; Habtewold, 2021). Food insecurity in the context of climate change incorporates low food availability and inadequate intake, variable access to food, and limited affordability (Teklewold et al., 2019). Increased climate variability, extreme events, and slow ongoing changes will affect food production, and thus food availability by reducing productivity and yields (Tilahun et al., 2023). This can, in turn, negatively influence access to the livelihoods and income of small-scale food producers and, through food price increases and volatility, the livelihoods of poor net food buyers, restricting access to food. Despite a huge rise in road density in Ethiopia, the food price index showed an increase from 1.66-1.87 over the years 1993-2020 (Berhane et al., 2021). In this period, the food price for cereals more than doubled by 27%. given the growing demand for food and the rapid rise in food prices in Ethiopia over the past decade (WFP, 2020). Impacts of climate change may further lead to potential changes in the nutritional quality of some foods (e.g. reduced concentration of proteins and some vitamins and

minerals), due to elevated temperature (Tesfaye et al., 2020). Moreover, climate change will affect food security and nutrition indirectly through its impacts on other socioeconomic factors, such as health, peace and mobility, poverty, water security, and changes in ecosystems and biodiversity. Thus, multiple climate risks and multiple climate risk drivers can interact with each other, creating compounding or cascading risks to food security (Ali et al., 2022; Hasan et al., 2018).

The impacts of climate change in Ethiopia may result in two categories of food insecurity outcomes. These outcomes correspond broadly to cyclical and transitory, and both are endemic in Ethiopia. On the one hand, droughts are the main triggers of transitory food insecurity. Such food insecurity is among the worst nationally; with record-breaking food assistance needs (Issahaku & Abdulai, 2020a). On the other hand, seasonality is a major driver of cyclical food insecurity, which is linked to erratic seasonal rainfall (Agbenyo et al., 2022). With declining productivity and crop yields as a result of extreme variability in seasonal rainfall (Wassmann et al., 2019), smallholder farmers who have small land holding often less than 1 hectare of land and who often depend on household labour and a small number of inputs for production will be hit hard (Myers et al., 2017; Wassmann et al., 2019). While there is growing concern about Ethiopia's food insecurity situation, reports indicated that about 15% of its population were undernourished by 2020, which is predicted to rise to more than 20% by 2025 (Meskel et al., 2020), putting food security at high levels risk (Meskel et al., 2020; Wekesa et al., 2018).

To sustainably address food insecurity and mitigate climate change risks, the adoption of Climate-Smart Innovations (CSIs) is believed to play a vital role in Ethiopia improving productivity, building climate resilience, and supporting food security (Kassa & Abdi, 2022). Such CSIs are often promoted by different stakeholders either jointly or independently. These include improved crop varietal selection which tolerates drought risks while increasing yields (Thornton et al., 2018), conservation tillage that leaves the previous year's crop residue to improve soil moisture and irrigation practices which improve return on investment while reducing risks of rainfall variability. However, the effectiveness and suitability of a CSI adoption depends on its type and specific socio-economic characteristics, biophysical contexts as well as its costs (Etana et al., 2020). As a result, there is no "one-size-fits-all" CSI that can exclusively generate benefits, if adopted, without incurring different types of costs. A specific CSI adoption can yield synergy in one context, especially when they have complementarity effects, but trade-offs in another context when they have conflicting effects (Ogola & Ouko, 2021). One important trade-off concern is the high opportunity costs of crop residue as mulches when it can be used

as livestock feed. Thus, the opportunity costs of applying crop residue as mulches to maintain soil health would be higher unless improved fodder productions are not adopted along with the conservation tillage with mulches. In economic terms, the adoption of conservation tillage may reduce the cost of inputs for production by reducing the expenses incurred for chemical fertilizers and pesticides which would deplete soil health in the long run (Ali et al., 2022; Gamage et al., 2023). This shows that the adoption of one CSI can simultaneously stimulate the adoption of another CSI by reducing the costs of application and production.

Despite ongoing efforts to promote a single or joint use of CSIs, the rate of adoption in Ethiopia is quite low, covering only 5-6% of arable land (Ali et al., 2022; Kassa & Abdi, 2022). Evidence shows that lack of household access to appropriate extension advice, lack of access to timely climate information, and poor training mechanisms have direct implications on low rate of CSI adoption (Issahaku & Abdulai, 2020; Teklewold et al., 2017; Wekesa et al., 2018). Consistent with this expression, Araya (2016) report that only a few farmers (5%) adopt both conservation tillage and irrigation practices in northern Ethiopia due to a lack of awareness and high-risk aversion behavior of farmers (Hadgu et al., 2019; Mekonnen et al., 2021). Similarly, lack of education, gender disparity, and land tenure insecurity are the reasons for the low adoption of soil water conservation practices (Pello et al., 2021). Such low adoption could result in low agricultural yields, limited economic capacity, and high exposure to agricultural risks, exacerbating vulnerability and food insecurity (Issahaku & Abdulai, 2020b; Teklewold et al., 2017).

There is extensive literature in Ethiopia on the adoption impacts of a single CSI, with divergent findings. The key pathways include the ability of conservation tillage to enhance soil health and maintain soil moisture (Hitayezu et al., 2017); (2) the positive effects of irrigation use on the farm return (Grabowski et al., 2019); and (3) the potential of crop choice in improving yields (Aryal et al., 2018). However, farmers do not only use a single CSI for a single stimulus in a particular plot, but rather they apply a combination of CSIs to face multiple household and farm-level constraints. Despite such potential synergies, studies evaluating the impact of a single and joint CSI adoption on household food security are very limited. This means comparing the household food security outcomes achieved because of CSI adoption at varying combinations and CSI non-adoption. Other studies report lower farm returns from plots treated with conservation tillage along with composting and animal manure application in Kenya (Wekesa et al., 2018), while Kurgat et al. (2020) found no significant effects. Similarly, Kassie et al. (2015) in Malawi, Kenya, and Ethiopia evidenced that certain terracing and soil bunds are likely to decrease average

crop yields by reducing the size of plots and making farming with oxen difficult. Mango et al. (2017) also report that crop residue application as soil mulches has a negative effect on livestock-dominated production systems that use crop residue as livestock feed. The mixed findings from these studies are the core problems that call to evaluate CSI adoption impacts on household food security outcomes in Ethiopia.

Another problem is that previous research estimates the drivers of CSI adoption depending only on observable farmer characteristics (Hadgu et al., 2019; Issahaku & Abdulai, 2020a). Such studies failed to take into account the effect of unobservable household-varying features and plot-varying characteristics, especially when farmers cultivate multiple plots (Habtewold, 2021). This has often resulted in overestimation or underestimation of the actual impact of CSI adoption. Given the fact that not all households are equally capable of adopting CSI (Falco, 2014), considering the unobservable drivers of CSI adoption is an essential precursor to indirectly understanding their impacts on household food security (Bedeke et al., 2019). In addition, past research analyzing the intersection between CSI adoption and food security outcomes typically includes only a few hundred observations based on cross-sectional survey data, which may not provide sufficient information on the variables of interest across time (Grabowski et al., 2019; Habtewold, 2021; Hadgu et al., 2019). One exception is a study by Tesfaye et al. (2020), who examined the food security outcomes of conservation agriculture based on the nationally representative sample of over 1000 Ethiopian households. However, the latter study did not explicitly address the CSI adoption issues that go beyond conservation agriculture using large datasets.

Given these gaps in knowledge, this study examines the factors influencing the adoption of CSIs and how such adoption impacts household food security in Ethiopia. In so doing, the study has made two main important contributions. Firstly, the study adds relevant value to the existing climate change research exploring the variations and relationships among households in adopting different CSI packages (Thornton et al., 2018). Secondly, the study contributes to the current studies (Mekonnen et al., 2021; Teklewold et al., 2017; Tesfaye et al., 2020) by evaluating the level of household food security of CSI adopters and non-adopters in response to different explanatory factors using a panel Endogenous Switching Regression (ESR) model (Tesfaye et al., 2020). The use of ESR is particularly important to account for potential endogeneity as a result of observable and unobservable heterogeneity, which may otherwise lead to suboptimal decision (Issahaku & Abdulai, 2020a). In particular, the study contributes to Ethiopia's Nationally-Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC),

which provides platforms to integrate issues of adaptation, mitigation, and food security (Mekonnen et al., 2021; Teklewold et al., 2017; Tesfaye et al., 2020).

### General objective

This study in general examines factors influencing a single and joint adoption of CSI and how this adoption impacts household food security in Ethiopia.

### Specific objectives

- To analyses factors influencing single and joint CSI adoptions by households; and
- To evaluate the effect of single and joint CSI adoptions on household food security.

# 2. Literature review

## Climate change risks in agriculture

Agriculture plays a major role in Ethiopia's economy, contributing 34% of the GDP, 75% of export value and 85% of employment (WBG, 2020). Although agriculture can cope with multiple shocks (Teklewold et al., 2019), smallholder farmers are most vulnerable to the climate change impacts (Habtewold, 2021). This is mainly due to their reliance on rainfed systems, which are subjected to seasonal fluctuations. High variability in rainfall can disrupt the growing season, amplifying water shortages and increasing the incidence of diseases (Teklewold et al., 2017). As a result of climate change, an increase in average temperatures is likely to promote crop productivity in highland areas, but it will decrease crop yields in lowland areas. This could in turn threaten the growth and yields of crops (Teklewold et al., 2019), reducing returns on investment (Hadgu et al., 2019) and inflating food prices in local markets (Issahaku & Abdulai, 2020). Such undesirable effects may exacerbate the frequency of extreme events like droughts and flood (Molua, 2011). In Ethiopia, drought is causing and is likely to further cause major economic loss, which jeopardizes past adaptation and development gains. This can further disrupt social networks by affecting pre-existing self-insurance systems such as the exchange of food (Rahut et al., 2021). In addition, flood is predicted to cause serious damage to cultivated crops and jeopardize land conservation efforts by hurting terraces, ponds, and plantations (Rahut et al., 2021; Serdeczny et al., 2017). Given the multiple climate change impacts, organizations like FAO encourage the holistic addressing of climate change issues through initiatives such as Climate-Smart Innovations (CSI).

## Single and joint CSI adoption

Building the resilience of smallholder farmers through innovations is a key to transitioning into sustainable agriculture. Innovation in this context means "strategies and technologies that are perceived as new or new ways of doing by units of adoption" (Rogers et al., 2003). With the need for adaptation efforts growing rapidly, and finance in short supply, innovations are required to make agriculture more resilient against multiple shocks (Antwi-Agyei & Amanor, 2022). Adoption in this study refers to the continuous use of either an individual or combined set of CSIs such as crop choices, conservation tillage, and irrigation practices (FAO, 2017). Such adoption does not only reduce ongoing climate risks but also increases productivity and improves household food security (Ferrer et al., 2023). For example, in low-rainfall areas where moisture stress is high, a promising CSI is the adoption of drought-tolerant crops *(Zea mays* L.) that reduce climate risks (Bedeke et al., 2019). To diversify cropping systems and reduce risks of soil depletion as well as improve dietary diversity legumes are largely adopted across agro-ecologies (Ali et al., 2022). Moreover, the adoption of conservation tillage is used as a potential CSI to manage soil ecosystems by keeping the soil surface covered with mulches (Wesenbeeck & Lammers, 2020). Accordingly, Sova et al. (2018) indicate that stubble retention from maize at harvest in Africa could help add soil organic matter and nutrients. Especially in areas having access to irrigation, the adoption of conservation tillage along with improved crop varieties are more resilient than mono-cropping (Mall et al., 2017).

CSI as a group of two or more indices has more advantages to achieve the maximum potential benefits and reduce trade-offs of the innovations compared to single CSIs. This approach can be effective by combining packages of different practices such as efficient use of land, water, and other environmental resources to attain higher yields, put more carbon in the soil, greater adaptation to prolonged dry spells and unpredictable rainfall seasons (Bongole et al., 2022). Gram et al. (2020) noted that greater return on investment can be achieved through the joint application of crop residue, and improved maize varieties and legumes compared to separate applications across the different countries in Sub-Saharan Africa. This shows that farmers can largely benefit from the mix of CSIs adopted whilst considering the interrelated nature of CSIs and other agricultural practices. Hence, the co-benefits of the CSI adoption as a package approach can in turn reduce climate change risks, build resilience, and improve household welfare through maximizing synergies. While synergy is a positive relationship between two or more CSIs, trade-offs are negative outcomes of the joint adoption, that result in a benefit higher or less than the sum benefits of a single CSI (Ogola & Ouko,

2021). However, as there is no silver-bullet innovation for all situations, one CSI can yield double or triple-win outcomes in one context, but trade-offs in another context. As a result, the adoption of combinations of some CSIs can increase labour use, emissions, and pollution, leading to trade-offs. Such trade-offs arise when a given CSI adoption promotes the achievement of the goal of a particular CSI while simultaneously impeding the achievement of other goals. Despite this, the advantages and weakness of the CSI adoption as two or more indices depend on the nature and multiplicity of stimuli, the type of innovation, and other socio-economic and biophysical characteristics, requiring context-specific research (Akpan & Zikos, 2023; Ali et al., 2022).

## Joint CSI adoption and climate change

Climate change is likely to cause multiple environmental risks requiring multiple solutions (Serdeczny et al., 2017). In drought-prone areas, farmers may jointly adopt drought-tolerant crop types along with other agronomic management practices to deal with extreme heat and dry-spell conditions (Issahaku & Abdulai, 2020; Thornton et al., 2018). However, Bongole et al. (2022) report that plant response to high temperature may vary with the duration of the temperature, degree of soil health, and the plant type. Accordingly, several drought-tolerant transgenic crops have been developed to withstand early and late season drought during crop growth season. However, the level of farmers' adoption of drought-tolerant crop varieties varies depending on the exposure of the soil to heat stress and the degree of the sensitivity of the crops to temperature and rainfall changes (Issahaku & Abdulai, 2020b; Mekonnen et al., 2021). As a result, the use of crop residue on the cropping farm may improve soil moisture while reducing risks of climate change (Ali et al., 2022; Ogola & Ouko, 2021). Efficient use of chemical fertilizers in conjunction with organic manure, recyclable waste, use of bio-fertilizers, and other locally available nutrient sources are essential for sustaining soil health and amelioration of the environment. Such practices conserve soil moisture in low rainfall areas due to increased infiltration rate and time of concentration (Meskel et al., 2020).

The joint adoption of irrigation and improved crop varieties in rainfed croplands is a prominent CSI that can provide a reliable supply of water to alleviate heat stress while improving yields (Hadgu et al., 2019). Depending on how irrigation water is distributed to crop types, cropping systems and varieties used as well as pre-existing soil moisture and fertility status there are different irrigation systems, including surface, sprinkler, and drip (Gong et al., 2021). While promoting the joint adoption of improved crop varieties and crop diversification, irrigations are important to address multiple risks of seasonal rainfall variability and heat stresses The suitability of irrigation systems for

croplands also depends on other factors including but not limited to energy requirements, maintenance, labor intensity, and capital and operation costs (Dicta & Begho, 2023). In a warmer climate, research suggests that investment in irrigation infrastructure and improved crop/animal breeding and soil water conservation are key to dealing with multiple climate shocks (Thornton et al., 2018; Wekesa et al., 2018).

## Joint CSI adoption and food security

Food security must be reoriented if they are to address multiple climate shocks through joint or single CSI adoption. Food security in this study refers to the availability and affordability of nutritious food items consumed in a specific time (FAO, 2017). Physical availability of food covers domestic production and the flow of food aid and exchange. The joint adoption of CSI may increase the size and quality of arable land suitable for agricultural production and improve soil fertility that affects crops and livestock, improve animal productivity in Africa (Meskel et al., 2020; Wekesa et al., 2018). Economic and physical access to food means being in employment with stable livelihoods and having the financial resources to access food. In rural communities, a single and joint adoption of CSI is an essential means to access food by improving income and reducing costs of investment (Ali et al., 2022; Kassa & Abdi, 2022). This can further drive several market factors and the prices of food as well as one's purchasing power, which directly influences one's access to food. Food consumption and utilization in the body depend on one's physiological needs, health status, and availability of access to clean water, sanitation, hygienic conditions, and health care. It helps to consume sufficient protein and energy (food quantity), and micro-nutrients for a balanced and nutritious diet (food quality, diet diversification) to attain better nutritional status (Ali et al., 2022). A single or joint adoption of CSIs such as irrigation and conservation tillage might affect utilization through income, expenditure, and consumption behavior. The decline in income is likely to cause a shift to resorting strategies like reduction in both quantity and quality of food through less consumption of protein sources, fruits, and vegetables (Adego et al., 2019; Habtewold, 2021). However, depending on the different social and biophysical contexts of farmers and the nature of innovation, the adoption rate may differ across households and locations (Bedeke et al., 2019). This variation implies food security outcomes (Ali et al., 2022; Tilahun et al., 2023).

## Measuring household food security

As food security is multidimensional, indices used to measure food security can combine the multiple dimensions of food availability, access, affordability, and utilization (Kassa & Abdi, 2022). A composite food security index helps the formulation of an index that is based on a variety of food security elements, and which can accurately include many dimensions of food security. Food security measurement based on a composite index has been promoted in empirical studies to measure food security by combining the Household Food Consumption Score (HFCS), Household Food Insecurity Access Score (HFIAS) and Consumption Coping Strategy Index (CCSI) and Household Expenditure Share (HES) as a proxy measure (Jambo et al., 2021; Kassie & Alemu, 2021; Tabe-Ojong et al.,, 2023).

The FCS aggregates household-level data on the diversity and frequency of food groups consumed over the previous seven days, which is then weighted according to the relative nutritional value of consumed food groups (Schouteten 2016). Based on this score, a household's food availability and nutritional dimensions of food security were captured. However, the HFCS does not consider the access and affordability dimensions of food security. Hence, the use of HFIAS can complement the HFCS by providing access and additional behavioural dimensions of food security. This includes accessibility or inaccessibility and the degree of anxiety involved in its acquisition, having eighteen items asked with a recall period of 30 days (Teklewold et al., 2017). However, the HFIAS fails to consider the effect of how households manage shortfalls in food availability and affordability of sufficient and nutritious food to sustain life. To complement this shortfall, the CCSI combines what households do when they cannot access enough food and/or enough money to buy food (Wassmann et al., 2019). CCSI is an indicator of household food security that proxies how households manage to cope with shortfalls in food for consumption. Despite this role, the CCSI does not capture the share of expenditure incurred when households buy food compared to the total expenditure for food and non-food items. HFES captures the share of total household expenditure (as a proxy of income) spent on food. This can reflect that the poorer and more vulnerable a household is, the larger the share of household income spent on food. Given this observation, the HFES is especially helpful in complementing the weaknesses of the HFCS, HFIAS, and CCSI, all of which can be combined to quantify food security.

## Climate change, CSI adoption, and food security

Climate change has both direct and indirect impacts on agricultural production systems. Direct impacts include effects caused by a modification of physical characteristics such as temperature levels and rainfall distribution on specific agricultural production systems (Issahaku & Abdulai, 2020). Indirect effects are those that affect production through changes in other species such as pollinators, pests, disease vectors, and invasive species (Ali et al., 2022). These indirect effects can play a major role. Impact translates from climate to the environment, to the productive sphere, to economic and social dimensions, bringing a range of additional risks on the availability of food, access to food, and utilization of food, as well as on the stability of these characteristics, for both farm and non-farm households. exposure to climate risks can trigger shocks to agricultural production and food availability, with risks of market disruptions, effects on supply and storage systems, as well as increases in agricultural commodity prices (food and feed), impacting accessibility and stability of food supplies for the entire population, particularly in countries with significant shares of the population spending a large part of their income on food (Amadu et al., 2020; Issahaku & Abdulai, 2020).

Agricultural systems can be made more resilient, by implementing measures that are very system- and local-specific. CSIs (such as cropping system diversification, soil, and water conservation, etc.) underpin ecosystem functioning and are salient for future progress in agricultural production through improved yields and nutritional quality (Habtewold, 2021). CSI can improve household food security and nutrition status under climate variability by increasing agricultural income (through higher yields or lower production costs) or by freeing up labor for alternative economic activities. Production of diversified food, especially among subsistence farmers, is also an important pathway through which CSI might improve nutrition. Cropping system diversification has the potential to cushion smallholders against food insecurity, contribute to dietary diversification, and increase farm income (Abegunde et al.,, 2022; Agbenyo et al., 2022).

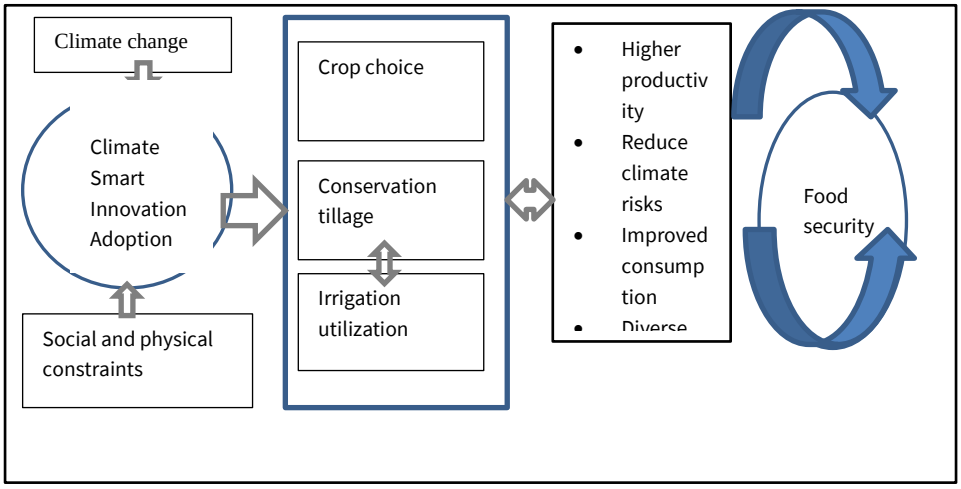
## Conceptual framework

The link between climate change, CSI adoption, and food security is quite complex as summarized in Figure 1. The adoption of CSI is driven by a range of factors such as climate change and other several socioeconomic and biophysical drivers (Teklewold et al., 2019). Climatic constraints include changes in temperatures, seasonal rainfall variability, and extreme events such as drought and flood, whereas socioeconomic and biophysical

constraints include changes in market structure, institutional systems as well as cropping and agricultural water use systems. Such constraints can adversely affect agricultural productivity, yields, household income, and cost of production and subsequently threaten household access to food and dietary diversity (Ali et al., 2022). To address multiple shocks, farmers use a range of CSIs such as crop choice, conservation tillage, and irrigation practices (Hadgu et al., 2019).

As synergies and co-benefits are characteristics of CSIs, the joint adoption of CSI directly enhances productivity by reducing production risks (Ogola & Ouko, 2021). Given the reliance of agriculture on the rainfed system in Ethiopia, the joint adoption of CSIs may improve farm return on investment and reduce climate change risks (Kassa & Abdi, 2022). For example, farmers who jointly use conservation tillage and crop choice are highly likely to diversify cropping systems (Wekesa et al., 2018). Such diversification does not only reduce the risks of climate change but also smooth consumption through promoting diverse coping strategies such as borrowing food, eating seed stock, and reducing meals. The joint adoption of irrigation and crop choice may lead to shifts in the types of food groups consumed or changes in the quantity of foods consumed (Teklewold et al., 2019). Production of diverse food groups including fruits and vegetables in cropping areas along with livestock may improve food availability (Pello et al., 2021). In this regard, they are often considered to sustainably improve farming practices for enhanced food security. However, the adoption of CSIs may vary across locations and farming systems affecting food security (Mekonnen et al., 2021; Wekesa et al., 2018).

**Figure 1. The link between climate-smart innovation adoption, their underlying drivers, and food security. Source: adapted from Lipper et al. (2014)**



# 3. Methodology

## Empirical strategy

**Model specification**: variations in household CSI adoption are often driven by farmers' preference, utility, and other socio-economic factors. Such variations can be examined based on the random utility approach (Greene, 2012). This approach entails that farmers can maximize the utility obtained from a specific combination of CSI by comparing the utility derived from the other alternative combinations (Wekesa et al. 2018). This means that farmers choose a CSI package that provides the highest expected value of outcome among the seven alternative CSI packages. This utility cannot be directly observed, rather it can be observed through household choices. Suppose that there are two choices j and k and the farm household's utility of two choices respectively be denoted by $U_j$ and $U_k$. The Common formulation for a simple random utility model is provided in Equation 1 as follows:

$$u_j = \beta_j x_i + \varepsilon_j \; and \; u_k = \beta_k x_i + \varepsilon_k \qquad 1$$

Where $u_j$ and $u_k$ have perceived utilities of CSI choices j and k, respectively. X is the vector of explanatory variables influencing the perceived desirability of the CSIs. $\beta_j and \beta_k$ are the parameters to be estimated, $\varepsilon_j and \varepsilon_k$ are the residuals. The observed CSI choice between j and k reveals which choice offers greater utility. If the expected utility of CSI choice j is greater than the utility of alternative choices k, the household decides to adopt choice j. As a result, the observed indicator equals 1 for $u_j > u_k$ and 0 otherwise (Greene, 2012).

To estimate CSI adoption impacts on household food security, both the Propensity Score Matching (PSM) methods and a panel Endogenous Switching Regression (ESR) model can be applied (Teklewold et al., 2017). Estimating the impact of adoption might yield biased and inconsistent estimates as adoptions are not assigned randomly. Farmers who decide to adopt a single or joint CSI may also be systematically different from those who do not adopt. As a result, a comparison between the two groups might be biased. This is because CSI adoption can be driven by unobserved farmer characteristics such as emotions and motivations as well as unobserved farm heterogeneities (e.g. soil fertility and land slope) which may correlate with household variables when a household cultivates multiple lands (Greene, 2012). In this regard, the use of PSM has a serious limitation in addressing problems of endogeneity, resulting in biased results (Issahaku & Abdulai, 2020). To account for endogeneity, this study applied a panel Endogenous Switching Regression (ESR) model which can be estimated in three stages (Greene, 2012).

***Stage 1: Multinomial adoption selection model:*** At this stage, the multinomial logit model (Greene, 2012) was applied to predict a single and joint adoption of Crop choice (C), Conservation tillage (T), and Irrigation use (I). Farmers were assumed to maximize their food security status $Y_i$ by comparing the gain provided by 7 m alternative CSI packages. The requirement for I to choose any CSI package, j over another alternative CSI package, m is that $Y_{ij} > Y_{im}$ and m ≠ j, that is j, provides a higher expected food security outcome than any CSI package. Let $Y^*$ be the latent variable that captures the expected benefits from the CSI adoption and is influenced by the observed household, plot, and climate characteristics and unobserved features. The latent variable is specified in Equation 2 as:

$$Y_{ij}^{*} = X_i\beta_j + \varepsilon_{ij} \qquad 2$$

Where $X_i$ captures the observed exogenous variables (household and plot characteristics), while the error term $\varepsilon_{ij}$ provides unobserved terms. The covariate vector $X_i$ is assumed to be uncorrelated with the unobserved feature $\varepsilon_{ij}$, that is, $E\left(\varepsilon_{ij} / X_i\right) = 0$, whereby error terms $\varepsilon_{ij}$ are assumed to be Gambel distributed and independent, under the assumption of the Independent Irrelevant Alternatives (IIA). The selection model (1) can be translated into a multinomial logit model in such a way that the probability of choosing a specific CSI $j(s_{ij})$ is:

$$s_{ij} = s\left(\varepsilon_{ij} < 0 / X_i\right) = \frac{\exp(X_i\beta_j)}{\sum^{j}{}_{M=1}\exp(X_i\beta_m} \qquad 3$$

***Stage 2: Multinomial Endogenous Switching Regression (MESR):*** This model was used to evaluate the impact of each response package on household food security outcomes by applying the selection bias correction model (Issahaku & Abdulai, 2020b). The selection bias correction model allows for addressing endogeneity by capturing unobserved household and plot-specific heterogeneities. This was estimated by calculating Inverse Mill's Ratios (IMR) from the estimated probabilities in the selection model. The impact of each combination of CSIs was estimated using OLS by including the IMR as additional covariates. Households have a total of 8 regimes, including the reference category (no adoption), C0T0I0) regime j = 1; Crop choice, C1T0I0 regime j=2; Conservation tillage, C0T1I0 regime j=3 and the remaining CSI

adoption packages regime i=j (Table 2). The food security outcome for each possible regime is defined as:

$$S_{i1} = z_i m_1 + z_{i1}^{*} \phi_j + \mu_{i1} \qquad \text{if i = 1} \qquad 4$$

$$S_{ij} = z_i m_i + z_{ij}^{*} \phi_j + \mu_{ij} \quad \text{if i = j} \quad \text{j= 2,3…8}$$

where, $S^{*}_{ij}$ represents the food security status, $z_i$ indicates a set of different explanatory variables, and the i[th] farmer in the first j and the error terms $\mu_{ij}$ are distributed with $E(\mu_{ij} / x, z) = 0$ and $\text{var}(\mu_{ij} / x, z) = \delta_j^{\,2}$. The variable $z^{*}$ refers to mean plot-specific characteristics such as soil fertility, plot slope, and drainage levels, and $\phi_j$ denotes the corresponding parameters to be estimated. This was used to address endogeneity due to unobserved heterogeneity of plot varying characteristics when a household cultivates multiple plots. A Wald test of the null hypothesis that the vector $\phi_j$ are jointly equal to zero is conducted to indicate the relevance of plot-specific heterogeneity. $S_{ij}$ is observed if, and only if, the selected innovation j is used, which occurs when $Y_{ij}^{*} > \max Y_{im}, m \neq 1$; if the error terms in Equation (3) and Equation (4) are not independent, resulting in biased estimates for Equation (4).

To ensure that estimates in $m_j$ in Equation (4) are unbiased and consistent, the inclusion of selection correction term derived from multinomial selection model is required. MESR assumes the following linearity assumption: $E(\mu_{ij} / \varepsilon_{i1} \ldots \varepsilon_{ij}) = \delta_j \sum_{m \neq j}^{\;j} r_j (\varepsilon_{im} - E(\varepsilon_{im}))$. By construction, the correlations between the error terms in Equation (3) and Equation (4) are zero. Thus, the outcome Equation (4) taking into consideration the choice made with bias correction can be expressed as follows:

$$S_{i1} = z_i m_1 + \delta_1 \lambda_1 + z_j^{*} \phi_j + \omega_1 \qquad \text{if i= 1} \qquad 5$$

$$S_{ij} = z_i m_j + \delta_j \lambda_j + z^{*}{}_j \phi_m + \omega_{ij} \qquad \text{if i= j}$$

$\delta_j$ is the covariance between $\varepsilon$ and μ while j is the inverse mills ratio computed from the estimated probabilities in Equation (5) as follows:

$$\lambda_j = \sum_{m \neq j}^{j} p_i \left[ \frac{p_{im} \ln(p_{im})}{1 - p_{im}} + \ln(p_{ij}) \right] \quad 6$$

where $p$ shows correlation coefficients of ε and μ, while $\omega_{ij}$ are error terms with the expected value of zero and constant variance. In the multinomial choice contexts, there are $j-1$ selection correction terms, for a particular alternative innovation. The standard errors in equation (6) will be bootstrapped to account for the heteroskedasticity arising from the generated regressions given by $\lambda_j$.

***Stage 3: Estimation of counterfactual and treatment effects*:** While comparing the estimated values of adopters and non-adopters**,** the average adoption effects of the single and joint CSI adoption on the household food security outcome were modeled based on the MESR. The estimates that are most commonly of interest are the Average Treatment Effect on the Treated (ATT) and the Average Treatment effects on the Untreated (ATU) (Masha et al. 2021). The ATT estimates the expected food security outcomes of (actual) CSI adopters if they do not adopt (counterfactual). The ATU estimates the expected food security outcomes of (actual) CSI non-adopters if they would adopt (counterfactual). In other words, the ATT measures the impact of CSI adoption on the food security of adopters in actual and counterfactual situations. ATU estimates the impact of CSI adoption on the food security of non-adopters in actual and counterfactual situations (Mango et al., 2017). Following Teklewold et al. (2017), ATT and ATU in the actual and counterfactual situations were calculated based on the following Equations (7-10):

*The actual expected value of outcome variables for adopters of a particular CSI is given by:*

$$E\left(S_{ij} / Z = j; X_{ij}, \phi_j, \lambda_{ij}\right) \text{ for j=2,3,4…J} \quad 7$$

*The actual expected value of outcome variables for non-adopters of a CSI is given by:*

$$E(S_{i1} / Z = 1; X_{i1}, \phi_1, \lambda_{i1}) \quad 8$$

*The counterfactual expected value of outcome variables for CSI adopters is given by:*

$$E(S_{i1} / Z = j; X_{ji}, \phi_1, \lambda_{ji}) \text{ for j=2,3,4…J} \quad 9$$

*The counterfactual expected value of outcome variables for CSI non-adopters is given by:*

$$E(S_{ji} / Z = 1; X_{1i}, \phi_j, \lambda_{1i}) \quad 10$$

ATT is expressed as the difference between Equation (7) and Equation (8) which is given by the

Equation 11:

$$ATT = E\left(S_{ij} / Z = j; X_{ij}, \phi_j, \lambda_{ij}\right) - E(S_{i1} / Z = 1; X_{i1}, \phi_1 \lambda_{i1}) \quad 11$$

where, ATT is the difference in the actual expected value of food security outcomes of adopters and the counterfactual expected value of food security of non-adopters if adopters had decided not to adopt, while $\lambda_j$ is the selection term that captures all potential effects of difference in unobserved variables.

ATU is expressed as the difference between Equation 8 and Equation 10 which is given by Equation 12:

$$ATU = \quad E(S_{i1} / Z = 1; X_{i1}, \phi_j, \lambda_{i1}) \; - \; E(S_{ji} / Z = 1; X_{1i}, \phi_1, \lambda_{1i}) \quad 12$$

where, the ATU is the difference in the actual expected value of food security outcome variables of non-adopters and the counterfactual expected value of food security outcome variables of non-adopters, while $\lambda_i$ is the selection term, together with the Mundlak device $\phi_j$, accounts for selection bias and endogeneity due to unobserved heterogeneity.

The validity of the MESR model requires exclusion restriction that is correlated with CSI adoption but does not play a role in the food security outcomes (Tesfaye et al., 2020). Thus, the information set of variables such as proximity to the local market and extension contacts were used as the selection instruments. The validity was checked using two tests. The first test has applied a probit model for adoption with instruments and other variables. The instruments were jointly validated as strong predictors for CSI adoption. The second is a falsification test that checks whether the instruments influence food security outcomes. The instrument was considered valid when the instrument variables had a statistically significant effect on CSI adoption and a statistically insignificant effect on the outcome variables. The exclusion restriction is rejected if the instrument variables have a statistically significant effect on the outcome equation (Thornton et al., 2018; Wekesa et al., 2018).

## Variables and hypothesis

### Dependent variables

***Selection variables***: As a selection variable, a single and joint adoption of climate-smart crop choices, conservation tillage, and irrigation practice were considered in the model, resulting in 7 dependent variables. These variables are categorized based on the data available. The base category is no adoption of any of the three CSIs. The adoption is defined as 1 if a household independently or jointly adopts any of CSI or, 0 otherwise. Crop choices include the use of drought-tolerant crops, changes in planting dates, diversification of improved crops with pulses, and crop rotation over the years. The use of crop residue as soil mulches along with manures and compost can be categorized under conservation tillage. Such CSIs can be combined with the use of climate-smart irrigation practices to improve food security and reduce climate change risks. Sprinkler irrigation, drip irrigation, and collecting rainwater are all examples of effective climate-smart irrigation practices that can be used to maximize water consumption efficiency and reduce negative effects on the environment. In times of drought or erratic precipitation, these methods guarantee crops receive enough water with minimal wastage, which characterizes irrigation practice as climate smart.

**Outcome variables**: As an outcome variable**,** food security is measured by composite indices as it has multidimensional outcomes. In this study, a combination of four indices was applied to measure food security outcomes.

***(1) Household Food Consumption Score (HFCS)***: The HFCS aggregates household-level data on the frequency of food groups consumed over the previous seven days, which is then weighted according to the relative nutritional value of consumed food groups. As a result, the HFCS is the sum of the frequency of food items consumed over the seven days multiplied by its weight. For instance, food groups containing nutritionally dense foods such as animal products are given greater weight than those containing less nutritionally dense foods like oils. Based on this score, a household's food consumption level can be classified into three: poor (0-21), borderline (21.5-35), and acceptable (>35).

***(2) Household Food Insecurity Access Score (HFIAS)*:** the HFIAS is uniquely indicated by the decreased access to sufficient food and behavioural dimensions of anxiety involved in food acquisition, having eighteen items asked with a recall period of 30 days (WBG, 2020). The respondent first asked an occurrence, i.e. whether the condition in the question happened at all in the past four weeks "(yes/no)". If the respondent answers "yes" to an occurrence question, a frequency-of-occurrence question is asked to

determine whether the condition happened rarely (once or twice), sometimes (three to ten times), or often (more than ten times) in the past four weeks. These measures are quantified and summarized into a scale, with 0 as the minimum score indicating households report no problem with food insecurity, and 27 as the maximum score with the highest problem of food insecurity.

***(3) Consumption Coping Strategy Index (CCSI):*** CCSI is an indicator that measures how households manage to cope with consumption shortfalls by relying on less preferred food, borrowing food, purchasing food on credit, reducing the number of meals eaten in a day, and skip meals (Schouteten, 2016). It is the frequency of how many days in the past week a household had to rely on the various coping strategies—ranging from "never" (0) to "every day" (7). That frequency score is then multiplied by the severity weight. That is, all the least severe strategies are weighted 1, the next group is weighted 2, etc. It is critical to ensure that the values for both the frequency and the severity influence the CCSI score in the same way. That is the higher the frequency, the higher the score. The greater the severity, the higher the severity weighting (Maxwell, 2008). A high score means extensive use of negative coping strategies due to increased food insecurity. The scores are divided into three categories: low HCSI score (0-50), medium (51-100) and high (over 100).

***(4) Household Food Expenditure Share (HFES):*** The share of food expenditure (as a proxy of income) over total expenditure was applied as an indicator of household food security. This can reflect that the poorer and more vulnerable a household is, the larger the share of household income spent on food. This observation is known as Engel's law, which demonstrates that as income rises, expenditure on food increases while expenditure on other things increases even more so that the share of total income spent on food declines.

### Explanatory variables

***Natural capital*** can be proxied by the levels of land fertility and land slope which influence the quality of the soil and subsequently influence a single and joint CSI adoption. Such farm-specific variables can further influence the quantity and quality of crop yields and hence determine food security. For this reason, farmers with a good fertility plot are less likely to adopt conservation tillage and crop diversification, but more likely to use improved crop varieties along with irrigation practices. Likewise, gently sloped plots are less prone to soil erosion than steeply sloped plots, reflecting variations in plot slope influences the single and joint CSI adoption driving household food security (Mashamaite et al., 2021). As a result, it was hypothesized that as the slope of

the plot decreases and becomes steeper, farmers are less likely to invest in costly improved crop varieties and irrigation management practices.

***Human capital:*** This can include household educational level, age, gender, and family size. Education is important for driving knowledge on new agricultural innovations that can improve food availability while reducing production risks. For example, the probability that a farmer may diversify cropping systems by combining improved maize varieties with pulses can be influenced by the household education level (Wekesa et al., 2018). Hence, farmers who have a higher number of schooling years are more likely to adopt a single and joint CSI which could improve their food security. Depending on labour availability, family size may negatively influence the likelihood of farmers adopting both the conservation tillage and the use of irrigation practices. However, the relationship between the age of the household and the adoption of CSI is often not straightforward (Wassie & Pauline, 2018). Young households often tend to adopt both irrigation and improved crop varieties, whereas old might be reluctant to adopt high-cost CSIs. Male-headed households are more likely to adopt CSIs and improve food security status compared to female-headed households. Female-headed households are more likely to invest in low-cost conservation tillage practices due to resource differentials and as a result tend to be less food secure (Thornton et al., 2018).

***Physical capital:*** This variable can be indicated by average land size in hectares, livestock holding size in Tropical Livestock Unit (TLU) as well as the distance from home to market in walking hours and variations in agroecology. A large landholding is expected to positively influence both the irrigation use and choices of improved crop varieties and cropping systems, which could improve yields, increase food availability and at the same time reduce climate change risks (Meskel et al., 2020). While promoting the use of animal manure for the soil, a large livestock holding may influence the adoption of both conservation tillage and crop diversification (Thornton et al., 2018). Distance from home to market is a proxy measure for access to market, and thus expected to influence the adoption of improved crop varieties (Tesfaye et al., 2020). In addition, normal rainfall in humid agro-ecology can enhance livestock holding by improving grass growth (Kurgat et al., 2020), which may negatively influence the use of conservation tillage (Tilahun et al., 2023). Given the rise in rainfall variability, farmers in a semi-arid agro-ecology are more likely to use improved crop varieties than farmers of humid zones (Bedeke et al., 2019).

***Financial capital:*** This represents monetary issues such as access to credit services, cost of innovation, and non-farm income sources. Such issues are highly likely to influence the adoption of improved crop varieties and/or irrigation practices, which may in turn affect household food security (FAO, 2017). As investment in CSI is often associated with expenses, the cost of innovation is likely to influence a single and joint CSI adoption and food security. Access to timely credit service is likely to influence the probability of the single and joint adoption of crop choices, conservation tillage, and irrigation practices. An increase in the costs of innovations is highly likely to affect the adoption of irrigation and improved crop varieties, but less likely to influence the adoption of conservation tillage. The cost of innovation is the total costs incurred in monetary terms for obtaining improved crop seeds and irrigation pumps. Farmers who have gained higher income from non-farm activities are more likely to adopt improved crop varieties and irrigation practices, which in turn influence access to food (Sova et al., 2018). Thus, diversification into non-farm activities is hypothesized to affect the likelihood of adopting CSI and hence indirectly to influence food security.

***Social capital****:* This can be defined as social connections, levels of trust in extension agents, plot tenure security, and membership in local organisations. Frequent and timely provision of extension advice by extension agents is assumed to build trust with farmers through building their confidence and hence affect the single and joint CSI adoption driving food security. Farmers who have connections with local groups are more likely to adopt conservation tillage along with improved crop varieties (Aryal et al., 2018). Household membership in farmer/women organisations is hypothesized to positively affect the adoption of CSI and food security (Sova et al., 2018). Ensuring household land use rights may increase the likelihood of using irrigation and crop choices (Thornton & Herrero, 2015). As a result, land tenure security is hypothesized to have a positive effect on both the adoption of CSI and food security.

***Climate variables:*** This includes climate variables such as monthly average daily temperature, monthly average daily rainfall, seasonal rainfall variability, and drought severity in combination with perceived rainfall changes over the past 31 years (1992-2022). As temperature increases farmers are more likely to use drought-resistant crop varieties and irrigation practices. The effect of change in monthly temperature on the joint CSI adoption is also based on the levels of variability in seasonal rainfall. Farmers who are more aware of and conscious of the early start and prolonged delay in seasonal rainfall are more likely to invest in irrigation along with drought-resistant crop varieties (Teklewold et al., 2017). An increase in perceived and actual seasonal rainfall

variability is expected to trigger a single and joint adoption of conservation tillage and cropping choices. Such joint adoptions are likely to improve agricultural productivity, enhance food availability, and reduce climate risks. In a more drought-prone environment, the joint adoption of improved crop varieties and irrigation practices may enhance food availability and affordability (Thornton & Herrero, 2015).

## Sampling strategy and data types

### Study site

The study was conducted in Ethiopia, with diverse agroecological conditions. It stretches from 3 to 15° northern latitude and from 33 to 48° eastern longitude. It covers a total surface area of 1.104 million $km^2$, of which 36.5% is agricultural land under crops and pasture (WBG, 2020). Ethiopia has experienced and will continue to experience significant impacts of climate change on agriculture (FDRE, 2011). Climate models show that warming in Ethiopia will depress agricultural yields, with stronger losses expected from rainfed crops (Ali et al., 2022). Despite projections showing an increase in rainfall, variability in seasonal rainfall will be more unpredictable (Etana et al., 2020). Such undesirable changes in temperature and rainfall may lead to more frequent droughts that could destabilize cropping periods, deplete cattle stocks, and amplify food insecurity (Ali et al., 2022; Belay et al., 2023).

## Sampling strategy

In this study, a panel Ethiopian Socio-economic Survey (ESS), a nationally representative survey dataset covering three waves (2013/14, 2015/16, and 2018/2019) was used (Tesfaye et al., 2020). ESS was administered by the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) in Ethiopia. Each datasets provide important information on issues of climate change and food security and they are publicly available, trusted, and used by several studies (Ali et al., 2022; Kassa & Abdi, 2022; Tilahun et al., 2023). The sampling strategy used for each wave was a two-stage probability sample. First, enumeration areas were selected using simple random sampling. Accordingly, a total of 290 enumeration areas were selected from the agricultural sample survey areas. The second stage of sampling was the selection of households to be surveyed in each sample using probability proportional to size techniques. The final sample involved 6770 rural households.

## Data types

Table 1 shows the information peculiarity, coverage, and relationship of the three waves of dataset used for analysis. The first wave (2013/2014) was designed to cover rural areas in Ethiopia excluding remote regions due to security problems by offering general information on agriculture, poverty, and market systems. The second wave (2015/2016) has covered remote regions of Ethiopia by including more detailed information on geo-referenced data on agricultural yields, soil, and land as well as food consumption and access to food. The third wave (2018/2019) provided additional information on irrigation practices and food marketing. In each wave, plot level information was georeferenced to include biophysical variables such as rainfall and drought in the analysis (Tesfaye et al., 2020). Each wave of ESS was gathered over the same months during the period of 5-9 months. As a result, variations in seasonality had not been an important issue. The ability to follow the same household over time makes the three waves a powerful dataset.

**Table 1: Peculiarity, coverage and relationship of the three waves of the dataset**

| Item | Wave 2013/2014 | Wave (2015/2016) | Wave 2018/2019 |
|---|---|---|---|
| Information Peculiarity | • General information on agriculture, poverty, market system food consumption and marketing | • More detailed information on geo-referenced data on agricultural yields, on soil and land as well as food consumption and access to food | • More specific information on improved methods of irrigation practices that improve irrigation use efficiency and food marketing.<br>• In addition, information on new methods of farming along with crop residue application was also provided in the third wave |
| Coverage | • Covering some rural parts of Ethiopia | • Covered all rural parts of Ethiopia by including the remote regions | • Covered all rural parts of Ethiopia including the remote regions |
| Relationship | • Each wave includes plot-level information geo-referenced to include biophysical variables such as rainfall and drought in the analysis<br>• Each wave of ESS was gathered over 5-9 months, including planting to harvesting during the rainy seasons.<br>• As the ESS datasets were collected at a similar time over the years, variations in seasonality had not been an important issue.<br>• The ability to follow the same household over time makes the three waves a powerful dataset. | | |

***Climate data:*** The historical maximum and minimum temperature and rainfall data were extracted from the Climate Hazards Group InfraRed Temperature with Station (CHIRTS) data (Verdin et al., 2020) and Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data (Funk et al., 2015), respectively. Both the CHIRTS and CHIRPs cover 31 years (1992-2022) quasi-global temperature and rainfall dataset that spans 50◦S − 70◦N. CHIRTS and CHIRPS incorporate 0.05◦ resolution satellite imagery with in-situ station data to create a gridded temperature and rainfall time series. Thin Plate Spline method of spatial interpolation was used to impute household-specific rainfall values (Falco et al, 2011). Then, the daily temperature data were aggregated into the monthly levels. From the rainfall data, the historical monthly average and coefficient of variation in rainfall were computed. MK Trend Test and Sen's Slope estimator were used to study the trend analysis of temperature. In addition, Following McKee et al. (1993), a rainfall anomaly index was applied to quantify the frequency and severity of droughts. This index was widely used as it is a very simple measure of drought frequency. Given the fact that meteorological stations in Ethiopia are sparse, self-reported data on rainfall change was included. The climate variables will help me to control for the effect of farmers' risk profiles and expectations on CSI adoption (Issahaku & Abdulai, 2020a).

# 4. Results and Discussion

## Climate data analysis

***Temperature trend tests*:** Table 2 shows the results of Mann Kendall's average monthly temperature trend tests and Sen's slope for the period 1992-2022. There is a statistically significant rise in maximum temperature during the months of the March, April and May over the period 1992-2022. A similar change in minimum temperature was recorded over the period. During these months farmers in Ethiopia undertake their land preparation and crop productions as these are months of short-rainy season. As a result, an increase in temperature during these months has a huge implication for crop production and food security.

**Table 2: Mann Kendall temperature trend tests and the Sen's slope for the period 1992-2022**

| Months | Tmax | | | Tmin | | | Tmean | | |
|---|---|---|---|---|---|---|---|---|---|
| | Z | P-value | Sen's slope | Z | P-value | Sen's slope | Z | P-value | Sen's slope |
| Jan | 2.161 | 0.076 | 0.054 | 0.921 | 0.022 | 0.034 | 2.133 | 0.043 | 0.034 |
| Fab | 2.322 | 0.023 | 0.083 | 0.782 | 0.033 | 0.066 | 1.392 | 0.005 | 0.045 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mar | 2.453 | 0.043 | 0.345 | 0.893 | 0.024 | 0.044 | 2.101 | 0.077 | 0.066 |
| April | 2.133 | 0.047 | 0.048 | 1.341 | 0.005 | 0.093 | 2.342 | 0.003 | 0.006 |
| May | 1.434 | 0.156 | 0.025 | 1.430 | 0.092 | 0.064 | 1.932 | 0.005 | 0.053 |
| Jun | 2.225 | 0.087 | 0.114 | 2.321 | 0.108 | 0.032 | 1.873 | 0.047 | 0.095 |
| Jul | 1.142 | 0.241 | 0.034 | −1.043 | 0.044 | 0.106 | 2.432 | 0.054 | 0.004 |
| Aug | 1.102 | 0.062 | 0.061 | 1.235 | 0.024 | 0.036 | 2.734 | 0.023 | 0.045 |
| Sep | 2.134 | 0.078 | 0.081 | −0.922 | 0.005 | 0.047 | 1.785 | 0.155 | 0.013 |
| Oct | 1.953 | 0.294 | 0.107 | 1.045 | 0.094 | 0.143 | 1.976 | 0.082 | 0.005 |
| Nov | 2.002 | 0.088 | 0.026 | 1.002 | 0.115 | 0.062 | 2.562 | 0.045 | 0.046 |
| Dec | 8.242 | 0.095 | 0.104 | 1.213 | 0.001 | 0.001 | 2.754 | 0.326 | 0.012 |
| Annual | 0.023 | 0.052 | 0.056 | 4.214 | 0.122 | 0.044 | 8.273 | 0.001 | 0.055 |

Source: Climate Hazards Group InfraRed Temperature with Station (CHIRTS) data (1992-2022)

***Rainfall trend tests:*** Table 3 shows the results of Mann Kendall average monthly rainfall trend tests and Sen's slope for the period 1992-2022. Monthly rainfall trends over the period 1992-2022 show a statistically significant decline in March, April, and May. This might be because of a high variability in the amount and duration of seasonal rainfall indicated by the results of the coefficient of variation. However, the change has slightly significantly increased during July and August, which might reflect a high intensity in rainfall associated with erosions and floods.

**Table 3: Mann Kendall rainfall trend tests and the Sen's slope for the period 1992-2022**

| Months | Z | P | Sen's slope |
|---|---|---|---|
| Jan | 1.03 | 0.075 | 0.124 |
| Fab | 2.24 | 0.17 | 0.322 |
| Mar | −2.15 | 0.144 | 0.077 |
| April | 1.46 | 0.23 | 0.044 |
| May | −1.96 | 0.34 | −1.013 |
| Jun | 2.23 | 0.05 | 2121 |
| Jul | 3.33 | 0.003 | 1.045 |
| Aug | 2.95 | 0.655 | 0.095 |
| Sep | −0.22 | 0.433 | −1.66 |
| Oct | 1.14 | 0.124 | 0.653 |
| Nov | 1.46 | 0.091 | 1.34 |

| | | | |
|---|---|---|---|
| Dec | 0.64 | 0.035 | 2.323 |
| Annual | 1.765 | 0.134 | 0.055 |

Source: Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data (1992-2022)

***Drought's frequency*:** The frequency of drought in Ethiopia over the period 1992-2022 was analyzed using the Standard Precipitation Index (SPI). Based on this analysis, when the SPI score of the period 1992–2022 is compared to the period 1985–1994, the occurrence of drought is much more frequent. This analysis matches the perceived responses of increased drought frequency. Based on the actual data, there has been an increase in the shortening of drought return periods over the past four decades, which is likely to continue in the future because of rising temperatures and erratic rainfall patterns that could adversely affect maize producers.

## CSI compositions

***Principal component analysis***: Table 4 contains the principal components and coefficient of linear combinations called loading. A visual inspection of Table 4 reveals that the four PCs explained 70.83% of the total variability in the dataset. The results indicated in Table 4 present a good fit, indicating that the PCA results highly explained the data. The first principal component explains 37.45% variance, whereas Components 2, 3, and 4 accounted for 23.45, 15.34 and 1.65% variance, respectively. This means that the first four components have more importance in explaining the variance in the dataset. The commonality column shows the total amount of variance in each variable retained in the four components.

**Table 4 Loading of the four components for the CSI compositions**

| Strategies | Comp1 | Comp2 | Comp3 | Comp4 | Communality |
|---|---|---|---|---|---|
| Drought resistant crops | 0.5683 | -0.3462 | 0.2532 | -0.2853 | 0.6210 |
| Changing planting dates | 0.6764 | -0.3844 | -0.3261 | -0.2365 | 0.6345 |
| Diversification of crops with pulses | 0.6123 | -0.3985 | 0.2983 | -0.3211 | 0.6024 |
| Crop rotation | 0.4321 | -0.7562 | 0.2574 | 0.3424 | 0.7210 |
| Use of crop residue | 0.3845 | 0.4322 | -0.4532 | 0.2321 | 0.6532 |
| Organic manures | 0.3682 | 0.5475 | 0.2632 | -0.3212 | 0.5639 |
| Compost | 0.2346 | -0.3543 | 0.2261 | -0.2545 | 0.5639 |
| Sprinkler | 0.3564 | 0.3654 | 0.3632 | -0.187 | 0.7563 |
| Drip irrigation | 0.2758 | 0.2385 | -0.3283 | 0.5321 | 0.6387 |
| Water harvesting | 0.5463 | 0.4328 | 0.3541 | 0.6321 | 0.7453 |
| Eigenvalues | 4.8764 | 3.023 | 2.432 | -0.2653 | |

| | | | | |
|---|---|---|---|---|
| Eigenvalues % contribution | 37.457 | 23.453 | 15.345 | 1.6563 |
| Cumulative % | 37.457 | 53.453 | 61.652 | 70.832 |

Comp: components. Four components are generated from the possible ten extracts using orthogonal rotation. Source: Sample household panel survey data.

## Dependent variable statistics

Table 4 presents the descriptive summary of the adoption of CSI packages in each year of the survey. The farmer could choose from 7 combinations of CSIs, with no adoption of any CSI package as a reference category. For example, the joint adoption of Crop Choice (C), Conservation Tillage (T), and Irrigation Utilization (I) is denoted as C1T1I1, and the joint adoption of none of all three CSIs is C0T0I0. Among the surveyed household heads (6770), about 32% of the respondents implement at least one CSI, while the remaining 68% of household heads do not adopt any of the CSIs. Among households that adopt CSI packages, about 18% adopted a combination of all three CSI packages (C1T1I1). The joint adoption of C1T1I1 slightly increased from 15% in 2015/2016 to 21% in 2018/2019, indicating low rates of CSI adoption. The proportion of households that adopt improved crop varieties along with irrigation practices significantly decreased from 39% in 2013/2014 to 25% in 2018/2019. The percentage of households that practice a combination of conservation tillage and irrigation is significantly diminished from 44% in 2013/2014 to 22% in 2015/2016. The significant declines in the use of combinations of CSIs are an indication of an unsustainable adoption.

**Table 5 Household adoption levels of Climate Smart Innovations (CSI) by year**

| S/no | Packages | CSI components | | | Year | | | Overall | |
|---|---|---|---|---|---|---|---|---|---|
| | | Crop Choice (C) | Conservation Tillage (T) | Irrigation Use (I) | 2013/14 | 2015/16 | 2018/19 | Mean | SD |
| 1 | C0T0I0 | - | - | - | - | - | - | - | - |
| 2 | C1T0I0 | √ | - | - | 0.33 | 0.24 | 0.44 | 0.34 | 0.08 |
| 3 | C0T1I0 | - | √ | - | 0.39 | 0.25 | 0.34 | 0.33 | 0.04 |
| 4 | C0T0I1 | - | - | √ | 0.27 | 0.21 | 0.25 | 0.24 | 0.02 |
| 5 | C1T1I0 | √ | √ | - | 0.11 | 0.39 | 0.34 | 0.28 | 0.16 |
| 6 | C1T0I1 | √ | - | √ | 0.39 | 0.29 | 0.25 | 0.31 | 0.10 |
| 7 | C0T1I1 | - | √ | √ | 0.44 | 0.22 | 0.25 | 0.30 | 0.13 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | C1T1I1 | √ | √ | √ | 0.17 | 0.15 | 0.21 | 0.18 | 0.03 |
| | Observations | | | | 699 | 727 | 730 | 2156 | |

Each component of CSI consists of binary variables of Crop Choice (C), Conservation tillage (T) and Irrigation use (I), where the subscript 1, refers if adopted, and 0 otherwise. The total observation: 6670 household heads, CSI adopters: 2156, CSI non-adopters: 4614. Source: Sample household panel survey data.

## Control variable statistics

Table 5 shows the definitions and summary statistics of control variables. As a natural capital, the levels of perceived soil fertility differ among single and joint CSI adopters. The joint CSI adopters have a good fertility plot compared to the single CSI adopters, reflecting variations in farm returns. In addition, farm return is subjected to the amount and variability of rainfall and droughts. In terms of coefficient of variation, the average rainfall variability index score is higher for the joint CSI adopters compared to the single CSI adopters.

**Table 6 Definitions and summary statistics of the variables to be used in the analysis**

| Variable | Description | CSI packages | | | | | | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C1T0I0 | C0T1I0 | C0T0I1 | C1T1I0 | C1T0I1 | C0T1I1 | C1T1I1 | Mean | SD |
| ***Natural capital*** | | | | | | | | | | |
| Poor fertile plot | =1 if reported poor fertility plot | 0.23 | 0.25 | 0.31 | 0.22 | 0.33 | 0.29 | 0.14 | 0.25 | 0.063 |
| Moderate fertile plot | =1 if reported medium fertility | 0.43 | 0.34 | 0.33 | 0.33 | 0.30 | 0.24 | 0.35 | 0.33 | 0.056 |
| Good fertile plot* | =1 if reported good fertility plot | 0.34 | 0.41 | 0.36 | 0.45 | 0.37 | 0.57 | 0.51 | 0.43 | 0.120 |
| Steep slope | =1 if reported steep slope plot | 0.32 | 0.22 | 0.21 | 0.34 | 0.32 | 0.22 | 0.27 | 0.27 | 0.035 |
| Medium slope | =1 if reported medium slope plot | 0.34 | 0.30 | 0.38 | 0.22 | 0.24 | 0.27 | 0.32 | 0.29 | 0.014 |
| Gentle slope* | =1 if reported gentle slope plot | 0.34 | 0.48 | 0.41 | 0.44 | 0.44 | 0.51 | 0.41 | 0.43 | 0.049 |
| ***Human Capital*** | | | | | | | | | | |
| Family size | Family size in adult equivalent | 2.22 | 1.43 | 1.97 | 1.57 | 2.1 | 2.55 | 1.39 | 1.89 | 0.586 |
| Gender | =1 if a household head is male | 0.89 | 0.85 | 0.91 | 0.84 | 0.87 | 0.79 | 0.90 | 0.86 | 0.007 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Age | Age in years | 52.46 | 41.28 | 43.91 | 46.99 | 39.37 | 40.95 | 39.76 | 43.53 | 8.980 |
| Education | Years of schooling | 5.32 | 6.44 | 4.35 | 7.80 | 4.43 | 5.44 | 6.44 | 5.74 | 0.791 |
| ***Physical capital*** | | | | | | | | | | |
| Land size (ha) | Total landholdings in hectare | 1.09 | 1.53 | 0.98 | 1.03 | 0.91 | 0.98 | 1.01 | 1.07 | 0.040 |
| Livestock size | Total livestock holdings in TLU | 3.44 | 5.21 | 4.91 | 3.22 | 2.42 | 3.76 | 4.21 | 3.88 | 0.544 |
| Market distance | Distance to market in walk hours | 1.50 | 0.70 | 1.10 | 0.90 | 1.30 | 0.60 | 0.95 | 1.01 | 0.388 |
| Semi-arid zone | =1 if located in semi-arid area | 0.33 | 0.25 | 0.23 | 0.33 | 0.36 | 0.27 | 0.27 | 0.291 | 0.042 |
| Sub-humid zone | =1 if located in sub-humid area | 0.35 | 0.31 | 0.38 | 0.24 | 0.25 | 0.29 | 0.38 | 0.314 | 0.021 |
| Humid zone* | =1 if located humid area | 0.34 | 0.44 | 0.39 | 0.43 | 0.39 | 0.44 | 0.35 | 0.397 | 0.007 |
| ***Financial capital*** | | | | | | | | | | |
| Access to microcredit | =1 if a household received credit | 0.340 | 0.44 | 0.38 | 0.33 | 0.43 | 0.48 | 0.51 | 0.42 | 0.120 |
| Non-farm income | Average non-farm income | 3360.5 | 4150.9 | 2830.5 | 5340.5 | 3390.8 | 4150.2 | 5920.7 | 4164.8 | 1803 |
| Cost of innovation | Average costs of innovation | 700.50 | 0 | 957.43 | 365.22 | 1234.01 | 452 | 344.12 | 579.04 | 251.19 |
| ***Social capital*** | | | | | | | | | | |
| Social connection | Number of trader connections | 5.323 | 6.11 | 9.29 | 7.34 | 10.10 | 11.09 | 9.71 | 8.42 | 3.10 |
| Trust in extension agents | =1 if a household trust agents | 0.432 | 0.56 | 0.67 | 0.46 | 0.41 | 0.52 | 0.59 | 0.52 | 0.113 |
| Membership status | =1 if reported membership | 0.511 | 0.47 | 0.38 | 0.55 | 0.41 | 0.39 | 0.51 | 0.46 | 0.001 |
| Plot tenure security | = 1 if plot is privately secured | 0.810 | 0.76 | 0.91 | 0.69 | 0.84 | 0.77 | 0.89 | 0.81 | 0.052 |
| **Climate variables** | | | | | | | | | | |
| Perceived rainfall shocks | Perceived rainfall variability | 0.65 | 0.74 | 0.51 | 0.55 | 0.77 | 0.84 | 0.79 | 0.693 | 0.071 |
| Average monthly rainfall | Monthly rainfall in mm | 147.32 | 141.54 | 144.91 | 140.61 | 142.41 | 139.88 | 145.82 | 143.21 | 1.061 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall variability | Coefficient of variation in rainfall | 0.78 | 0.61 | 0.56 | 0.80 | 0.71 | 0.79 | 0.82 | 0.72 | 0.028 |
| Average monthly temperature | Monthly temperature in $^{O}C$ | 26.4 | 29.33 | 31.54 | 27.43 | 26.86 | 25.22 | 29.01 | 25.1 | 27.21 |
| Drought frequency | Rainfall anomaly index | 0.14 | 0.11 | 0.29 | -0.31 | -0.23 | -0.54 | -0.16 | -0.15 | 0.014 |
| Observation (adopters) | | 355 | 337 | 339 | 350 | 269 | 265 | 241 | 2156 | |

Each CSI packages consists of binary variables of Crop Choice (C), Conservation tillage (T) and Irrigation use (I), where the subscript 1, refers if adopted, 0 otherwise. The total observation: 6670 household heads, CSI adopters: 2156, CSI non-adopters: 4614. TLU= is Tropical Livestock Unit, which is calculated through standard conversion factors of Storck et al. (1991): Calf (0.4), Cow (0.75), Ox (1.0), Sheep and Goat (0.13), and Poultry (0.06), SD= standard deviation. Negative values indicate below normal rainfall, indicating droughts. Source: Sample household panel and actual climate data (1992-2022).

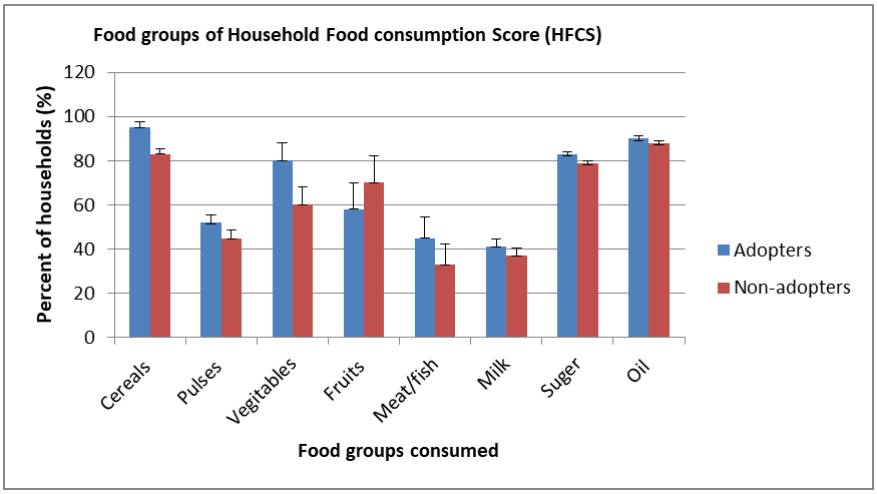
Based on the drought severity index, joint CSI adopters have lower drought severity compared to single CSI adopters. Gender differential in terms of access to improved technologies and information can be correlated with variations in CSI adoption. Among the CSI packages, most male-headed households adopt irrigation practices either independently or jointly with other CSIs. In addition to gender, the education level of the household head may be correlated with CSI adoption in terms of boosting their ability to obtain, decode, and understand information. On average, the educational level of a household is 5.74 years of schooling, with an average age of 43.3 years. The average land size of households jointly adopting CSI is less than the average land size of all households. Households having access to credit range from 33%- 51% across CSI packages, with a mean value of 0.42. The majority of credit users reported having adopted combinations of crop choice, conservation tillage, and irrigation practices. On average, households who were involved in non-farm activities such as petty trading and casual work obtained about 4164.80 Birr, which is higher among the joint CSI adopters. Membership in farmer organizations facilitates the flow of important information on new agricultural innovations while building farmers' confidence to apply extension advice. Among the CSI adopters, about 46% have membership status in farmer organizations which foster information flow and maintain agricultural sustainability. In terms of plot tenure security, about 81% of households reported that their plots are privately secured.

Among CSI adopters, most households who adopt C1T1I0 reported to have secured plot tenure.

## Outcome variable statistics

***Household Food Consumption Score (HFCS)***: Figure 2 shows the percentage distribution of food groups consumed by adopters and non-adopters over the previous 7 days of the survey year. Despite a slight difference, about 95% of CSI adopters and 83% of non-adopters reported having consumed cereals as their main staple foods. The percentages of households who adopt CSIs are significantly different from households who do not adopt CSI in terms of vegetable consumption. This implies that the adoption of CSIs such as the use of irrigation and conservation tillage practices might be important for vegetable production. However, this is not true for the CSI adopters and non-adopters in terms of fruit consumption. The percentages of CSI adopters who reported having consumed fruit over the past 7 days are significantly less than the percentages of non-adopters.

**Figure 2. Distribution of food groups by adopters and non-adopters over the previous 7 days of the survey year**

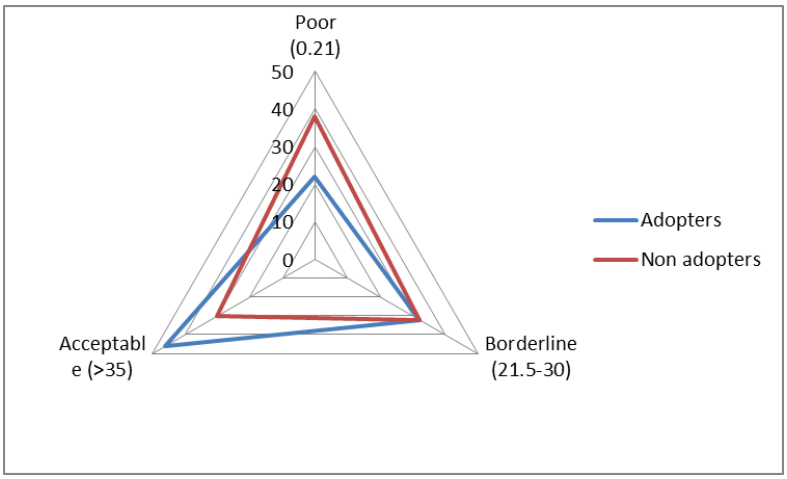



Note: The food groups are used to quantify HFCS along with their standard nutritional importance. Source: Sample household of the panel survey data.

Figure 3 shows the distribution of household food consumption rates by CSI adopters and CSI non-adopters over the previous 7 days of the year. The majority (46%) of CSI adopters have an acceptable rate of food consumption score compared to CSI non-adopters. This can reflect that as compared to non-CSI adoption, CSI adoption is more important to enhance food security by improving the frequency of individual foods consumed and the number of days that a specific food item has been consumed by the household in the past

week. Such consumption might be, however, highly dependent on the food preference, test, and their underlying nutritional importance. Conversely, farmers who do not adopt CSI have a poor rate of household food consumption compared to CSI adopters. Thus, this can be described that low CSI adoption is highly correlated with a poor rate of household food consumption.

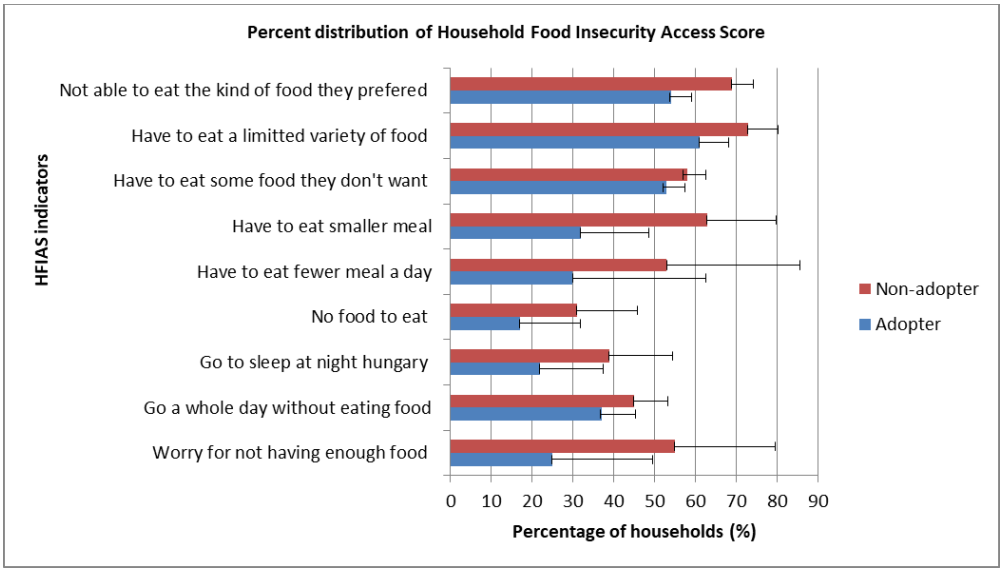
**Figure 2. Distribution of food consumption levels by CSI adopters and non-adopters over the previous 7 days of the survey year**




Note: The food groups are used to quantify HFCS along with their standard nutritional importance. Source: Sample household of the panel survey data

***Household Food Insecurity Access Score (HFIAS):*** Figure 4 shows the distribution of Household Food Insecurity Access Score (HFIAS) indicators implemented by adopters and non-adopters. Among the surveyed respondents, the majority (55%) of non-adopters worry about not having enough food compared to non-adopters, with a statistically significant difference. A smaller number of adopters reported having to eat a fewer meal a day over the past 30 days compared to non-adopters, implying the use of CSIs such as improved crop varieties and irrigation utilization might have improved the availability of food for the CSI adopters. A statistically significant group of CSI non-adopters must eat a limited variety of foods compared to the group of CSI adopters. The joint adoption of CSIs such as the use of irrigation and conservation tillage practices along with improved variety do not only improve access to food but also enhance the diversity of food consumed in the household.

**Figure 3. Distribution of Household Food Insecurity Access Score (HFIAS) by adopters and non-adopters over the previous 30 days of the survey year**




Source: Sample households of the panel data

***Consumption Coping Strategy Index (CCSI):*** Table 3 presents the distribution of indicators of CCSI by CSI adopters and non-adopters. The percentage of households who borrow food from relatives/friends over the previous 7 days is significantly higher among non-adopters compared to adopters. In terms of purchasing food on a credit basis, non-adopters constitute a significantly higher percentage compared to adopters. This implies that most adopters do not rely on such consumption coping strategies in the face of food shortage.

**Table 7. Descriptive statistics of Consumption Coping Strategy Index (CCSI) scores by adopters and non-adopters of Climate Smart Innovations (CSIs)**

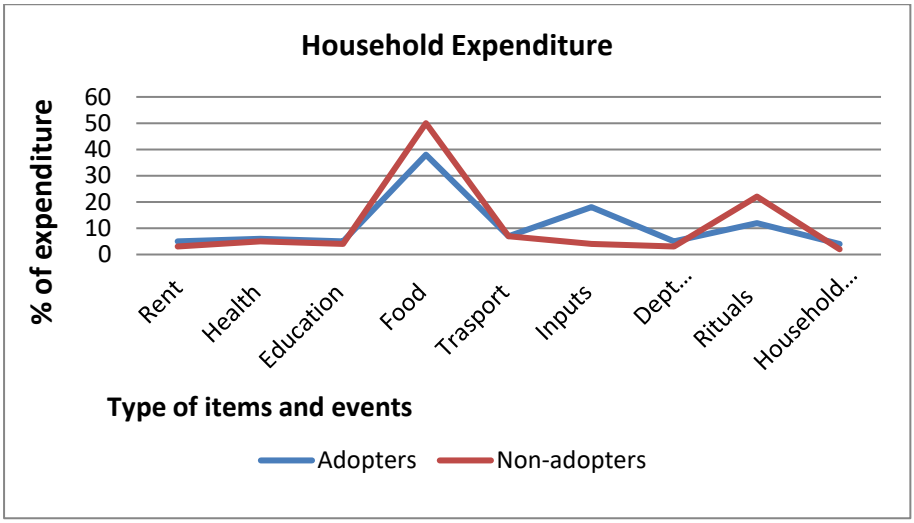
| CCSI Indicators | CSI adoption category | | |
|---|---|---|---|
| | Adopters | Non-adopters | t- value |
| Borrow food from relatives and/or friends | 0.52 | 0.69 | 3.59** |
| Purchase food on credit basis | 0.14 | 0.28 | 2.12** |
| Gather wild food and/or harvest immature crops | 0.33 | 0.39 | 0.87 |
| Consume seed stock held for next season | 0.31 | 0.38 | 0.98 |
| Send household members to eat in neighbors | 0.19 | 0.23 | 0.63 |
| Restrict consumption by adults | 0.32 | 0.23 | 1.83* |
| Feed more working members | 0.16 | 0.29 | 2.34** |

| | | | |
|---|---|---|---|
| Reduce the portion of meals eaten in a day | 0.32 | 0.18 | 2.48** |
| Skip mealtimes without eating | 0.22 | 0.33 | 1.88* |
| Observations | 2156 | 4614 | |

Note that **, * the difference is statistically significant at 5% and 10% probability level, respectively. Source: Sample household panel data.

***Household Food Expenditure Share (HFES):*** Figure 5 shows the distribution of the share of expenditures incurred to buy food over non-food items as well as other social events. The majority (50%) of CSI non-adopters spend a higher share of their money on food items, whereas 22% of CSI adopters spend their share of money to purchase agricultural inputs such as improved crop varieties and irrigation practices. In addition, a greater share of money is spent on social rituals among CSI non-adopters compared to CSI adopters. This may help one to reflect on the social and cultural dimension of food insecurity in terms of the share of expenditure on food compared to non-food items by the CSI adopters and CSI non-adopters.

**Figure 4: The distribution of household expenditures on food and non-food items by Climate smart innovation adopters and CSI non-adopters**




Source: Sample household panel data

## Econometric model results

### Drivers of single and joint CSI adoption

Table 4 presents the results of determinants of single and joint CSI adoption by the households. The reference category is the non-adoption of CSI (C0T0I0). The selection model (multinomial probit model) fits the data well, with the Wald $\chi^2$ (2150) = 4331; p> $\chi^2$=0.000, rejecting the null hypothesis that all the regression coefficients are jointly equal to zero. The instruments (proximity to

the local market and levels of trust in extension agents) applied to identify the MESR model are also found to be jointly significant. A falsification test on the instruments excluded also indicated that the instruments jointly affected CSI adoptions, but not the food security outcomes. The test of the IIA assumption indicates that the model is correctly specified as the Hausman specification test failed to reject the null hypothesis of no systematic difference between coefficients ($\chi 2=2.37$, $p=0.001$). This implies that the omission of one alternative from the estimation does not alter the coefficients of variables of the remaining alternatives significantly.

As expected, compared to farmers who have good fertility plots, households having poor fertility plots are highly likely to adopt conservation tillage only and crop choices and conservation tillage jointly. Poor soil fertility may stimulate farmers to invest in sustainable soil fertility management strategies such as crop diversification using legumes and organic fertilizers in combination with inorganic ones. Such fertility management practices are more beneficial for farmers who adopt improved crop varieties. Although there is no statistically significant effect on the joint CSI adoptions, the nature of the plot slope significantly influences the adoption of crop choices only for farmers cultivating in steeply sloped areas. This might be because steep slopes are more prone to erosion compared to gentle slopes, favoring CSI non-adoption. Similar findings have been reported in Ethiopia by (Teklewold et al. 2017) and in Kenya by (Wekesa et al., 2018), underscoring the importance of capturing plot-specific features in developing climate-smart agricultural plans.

Findings also showed a positive and strong effect of family size on the joint adoption of conservation tillage and irrigation practices. The strong effect of family size on the adoption of irrigation practices such as rainwater harvesting, and pond and river diversions is in line with our previous expectation, the fact that irrigation utilization is highly labor and knowledge-demanding innovation. Female-headed households are more likely to adopt low-cost innovations such as conservation tillage compared to male-headed households who adopt high-cost innovations such as irrigation and improved crop seeds. An increase in the age of the household positively and significantly increased the probability of adopting crop choices and conservation tillage but significantly increased the probability of adopting irrigation practices only. More aged households tend to reject innovations but rely on the use of new practices in old mechanisms. The coefficient of variable education is positive for the adoption of both single and joint CSIs, including the adoption of irrigation practices, and joint adoption of crop choices and conservation tillage as well as the joint adoption of crop choice, conservation tillage, and

irrigation practices. These findings are in line with the results of (Mango et al., 2017) in South Africa, (Issahaku & Abdulai, 2020b) in Ghana and (Wekesa et al., 2018) in Kenya, which showed a significant effect of household socio-economic characteristics on CSI adoption.

The margin of variable land size is positive and significant for the adoption of crop choice only and irrigation practices, implying an increase in land size could enhance adoption. However, for farmers who jointly adopt crop choices and conservation tillage, an increase in land has a negative significant effect on adoption. An increase in livestock holding positively and significantly enhances the joint adoption of conservation tillage, crop choice, and irrigation practices. Increased income generated from livestock can be reinvested in the adoption of the Joint CSIs, which can improve productivity and reduce climate change risks. These findings support the results of (Thornton & Herrero, 2015) in Sub-Saharan Africa who indicated that an increase in livestock holding positively influences agricultural income which in turn fosters the implementation of climate-smart practices. However, market distance from home in walking hours appeared to negatively affect the adoption of crop choices. This result coincides with the findings of ( Habtewold, 2021) who revealed that markets located far away may increase transaction costs and subsequently reduce the probability of adopting CSI either independently or jointly.

As expected, the marginal effect of variable access to micro-credit service is positive and significantly different from zero, suggesting that household access to credit increases the likelihood of adopting crop choices only, crop choice in combination with the use of irrigation, and the joint adoption of crop choices, conservation tillage, and irrigation. Also, the marginal effect of non-farm income is positive and significant for the joint adoption of crop choices and irrigation practices. These findings support the notion that financial capital plays a significant role in promoting the joint CSI adoption (Tesfaye et al., 2020). Furthermore, the variable representing the levels of trust in extension agents has a positive and significant effect on the joint adoption of crop choice and conservation tillage along with irrigation use. Membership in social groups positively and significantly influences a single and joint adoption of crop choices, conservation tillage, and irrigation practices. Despite owing to dark-side of social capital (Pretty & Ward, 2001), membership in local groups and networks can foster timely communication and information exchange to facilitate the CSI adoption and sustainable technology intensification.

**Table 8. Determinants of CSI adoptions: marginal effect**

| Variables | C1T0I0 | | C0T1I0 | | C0T0I1 | | C1T1I0 | | C1T0I1 | | C0T1I1 | | C1T1I1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ME | SE | ME | SE | ME | SE | ME | SE | ME | SE | ME | SE | ME | SE |
| ***Natural capital*** | | | | | | | | | | | | | | |
| Poor fertile plot | 0.013 | 0.022 | 0.431** | 0.213 | 0.021 | 0.130 | 0.210** | 0.311 | 0.213 | 0021 | 0.310 | 0.211 | 0.421*** | 0.233 |
| Moderate fertile plot | 0.231 | 0.082 | 0.143 | 0.211 | 0.0510 | 0.006 | 0.221 | 0.230 | 0.0940 | 0.321 | 0.053 | 0.201 | 0.231 | 0.021 |
| Steep slope | -0.045** | 0.002 | 0211 | 0.023 | 0.301 | 0.013 | 0.189 | 0.217 | 0.092 | 0.321 | 0.210*** | 0.061 | 0.512 | 0.038 |
| Medium slope | 0.091 | 0.421 | 0.541 | 0.065 | 0.183 | 0.321 | 0.342 | 0.110 | 0.381* | 0.054 | 0.0432 | 0.521 | 0.096 | 0.218 |
| ***Human Capital*** | | | | | | | | | | | | | | |
| Family size | 0.033 | 0.022 | 0.012 | 0.020 | -0.005 | 0.019 | 0.002 | 0.018 | -0.017 | 0.019 | 0.214*** | 0.117 | -.007 | 0.019 |
| Gender | 0.330** | 0.152 | 0.065 | 0.0114 | 0.113 | 0.032 | 0.323 | 0.112 | -0.092 | 0.116 | 0.193 | 0.113 | 0.231** | 0.134 |
| Age | 0.003 | 0.005 | -002 | 0.004 | 0.162 | 0.098 | -0.123** | 0.105 | -0.001 | 0.002 | -0.005 | 0.003 | -0.001 | 0.003 |
| Education | 0.024 | 0.107 | 0.069 | 0.098 | 0.133** | 0.097 | 0.210*** | 0.187 | 0.104 | 0.088 | -0.074 | 0.103 | 0.165*** | 0.082 |
| ***Physical capital*** | | | | | | | | | | | | | | |
| Land size (ha) | 0.196*** | 0.104 | 0.039 | 0.043 | 0.142*** | 0.103 | 0.043 | 0.045 | 0.091 | 0.003 | 0.032 | 0.091 | 0.031 | 0.102 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Livestock size | 0.004 | 0.032 | 0.003 | 0.004 | 0.029 | 0.010 | -0.421* | 0.102 | 0.054 | 0.033 | 0.041 | 0.051 | 0.190** | 0.110 |
| Market distance | -0.103** | 0.008 | 0.013 | 0.021 | 0.281** | 0.112 | 0.109** | 0.156 | 0.033 | 0.08 | 0.162** | 0.112 | 0.101** | 0.008 |
| Semi-arid zone | -0.211 | 0.103 | 0.209 | 0.100 | -0.122 | 0.091 | 0.152 | 0.111 | 0.011 | 0.121 | 0.321* | 0.103 | 0.206 | 0.176 |
| Sub-humid zone | 0.133 | 0.061 | -0.196 | 0.065 | 0.073 | 0.021 | 0.018 | 0.015 | 0.012 | 0.091 | 0.122 | 0.041 | -0.174 | 0.101 |
| ***Financial capital*** | | | | | | | | | | | | | | |
| Access to microcredit | 0.244** | 0.091 | 0.128 | 0.011 | 0.123 | 0.012 | 0.091 | 0.120 | 0.192* | 0.126 | 0.123 | 0.087 | 0.311*** | 0.122 |
| Non-farm income | 0.063 | 0.022 | -0.154* | 0.091 | -0.130 | 0.029 | 0.098 | 0.009 | 0.203*** | 0.111 | 0.013 | 0.006 | 0.112 | 0.061 |
| Cost of innovation | 0.091 | 0.032 | 0.055 | 0.021 | 0.075 | 0.037 | 0.087 | 0.011 | 0.211** | 0.191 | 0.092 | 0.064 | 0.243** | 0.072 |
| ***Social capital*** | | | | | | | | | | | | | | |
| Social connection | 0.015 | 0.007 | 0.090 | 0.043 | 0.023 | 0.04 | 0.111** | 0.091 | 0.022 | 0.006 | 0.037 | 0.010 | 0.181** | 0.103 |
| Trust in extension agents | 0.401* | 0.121 | 0.210 | 0.102 | 0.209** | 0.170 | 0.291** | 0.126 | 0.301*** | 0.254 | 0.344*** | 0.210 | 0.310*** | 0.210 |
| Membership status | 0.026 | 0.015 | -0.032 | 0.091 | 0.021 | 006 | 0.162** | 0.021 | 0.125* | 0.012 | 0.011 | 0.004 | 0.031 | 0.014 |
| Plot tenure security | -0.109 | 0.012 | -0.013 | 0.211 | 0.012 | 0.005 | 0.051 | 0.033 | 0.231** | 0.105 | 0.044 | 0.015 | 0.095 | 0.013 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Climate variables*** | | | | | | | | | | | | | | |
| Perceived rainfall shocks | -0.133 | 0.046 | -0.210* | 0.101 | -0.211** | 0.019 | -0.198* | 0.103 | -0.061 | 0.008 | 0.231* | 0.126 | -0.321** | 0.128 |
| Average monthly rainfall | 0.042*** | 0.115 | 0.035 | 0.087 | 0.105 | 0.033 | 0.091 | 0.062 | 0.018 | 0.054 | 0.097 | 0.106 | 0.033 | 0.029 |
| Rainfall variability | -2.810** | 0.982 | 1.923 | 1.620 | 1.322 | 1.220 | 2.101*** | 1.876 | 0.621 | 0.132 | 1.292 | 0.784 | 2.132** | 1.091 |
| Monthly temperature in $^{O}C$ | 0.65 | 0.34 | 0.032 | 0.12 | 0.421 | 0.011 | 1.232* | 0.871 | 0.45 | 0.110 | 0.51 | 0.334 | 1.92** | 0.98 |
| Drought frequency | 0.132 | 0.210 | 0.021 | 0.343 | 0.201 | 0.126 | 0.232 | 0.190 | 0.633*** | 0.432 | 0.322 | 0.092 | 0.045** | 0.236 |
| Constant | -0.283 | 7.104 | -12.341* | 4.234 | -5.343 | 5.76 | 4.932 | 2.029 | -3.381 | 6.021 | -2.321 | 3.101 | -6.012 | 2.021 |
| Joint significance of selection instruments $\chi^2$ | 34.6*** | | 58.11** | | 23.44** | | 98.50*** | | 21.13 | | 56.33** | | 87.12*** | |
| Joint significance of time varying covariant $\chi^2$ | 13.6** | | 10.4 | | 12.3* | | 21.1*** | | 15.3** | | 10.9 | | 9.01 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Joint significance of location $\chi^2$ | 18.9* | 32.1** | 45.3*** | 12.7 | 102.4*** | 30.2** | 140.3*** |
| Number of observations | 355 | 337 | 339 | 350 | 269 | 265 | 241 |

Wald $\chi^2$ (2150) = 4331; p> $\chi^2$=0.000

Each component of CSI consists of binary variables of Crop Choice (C), Conservation tillage (T) and Irrigation use (I), where the subscript 1, refers if adopted, 0 otherwise. The total observation: 6670 household heads, CSI adopters: 2156, CSI non-adopters: 4614. ME is marginal effect, SE is standard error. ***, **, * the difference is statistically significant at 1%, 5% and 10% probability level, respectively. Source: Sample household panel data.

This result agrees with the findings of (Issahaku & Abdulai, 2020a) in northern Ghana who indicated that social network is an important variable in driving the joint adoption of climate-smart agricultural technologies to support food security. The marginal effect of variable farmers' perception of seasonal rainfall variability in terms of frequency, timing, and amount is significant, but negative effect on the joint adoption of crop choice and conservation tillage. This suggests the necessity to upgrade farmers' awareness of the trends and variability of seasonal rainfall. Conversely, the marginal effect of the latter variable has a positive impact on the joint adoption of conservation tillage and irrigation practices. This finding converges with results obtained from actual rainfall data analysis. The positive marginal effect of average seasonal rainfall on the adoption of crop choices only implies that insufficient rainfall and/or rainfall variability is the main trigger for the joint adoption of CSIs. Interestingly, the marginal effect of drought frequency has a positive and significant impact on the joint adoption of crop choices and irrigation practices as well as the joint adoption of crop choices, conservation tillage, and irrigation use. Similar findings are revealed by the study of (Mango et al., 2017) in South Africa, (Kurgat et al., 2020) in Tanzania and (Wainaina et al., 2016) in Kenya who reiterated that adoption of climate adaptation strategies are significantly driven by both climatic and socio-economic factors.

## Effects of single and joint CSI adoption

Table 5 presents the average treatment effect on the treated and untreated households to indicate the impact of single and joint CSI adoptions on households' food security outcomes. In this study, the expected food security of CSI adopters and CSI non-adopters if they would have not adopted and if they would have adopted, respectively are presented. Consequently, the value of ATT and ATU with corresponding levels of significance under the actual and the counterfactual situation is provided.

Results show that the adopters of conservation tillage only have higher (31.92) values of HFCS while their counterparts showed lower (28.73) values and the difference was statistically significant. Higher (39.01) values of HFCS is gained when farmers jointly adopt crop choices and conservation tillage, while their counterparts obtained lower values (38.11). The difference is statistically significant at 1% probability level. In addition, the joint adopters of crop choice and conservation tillage have gained greater (14.91) and significant HFCS values compared to their counterparts which, however, do not show any significant mean difference. In most counterfactual cases, CSI adopters and non-adopters would have higher HFCS if they had adopted. These findings are in agreement with the results of (Prasad et al., 2016) in Rwanda and (Chichongue et al., 2020) in Mozambique showed that the adoption of climate-

smart agricultural practices can enhance household food consumption rate. However, our findings contradict the results of (Issahaku & Abdulai, 2020a) in Zambia in terms of returns to the number of CSIs jointly adopted. This is supported by the positive, but non-significant gains for the joint adopters of the three CSIs, including crop choice, conservation tillage, and irrigation practices. This result is in agreement with the findings of (Teklu et al., 2022) in northern Ethiopia revealed that adoption of higher combinations of CSI may not always result in better food security outcomes.

Results in Table 5 reveal that the adopters of both conservation tillage only and crop choice only have lower (13.98) HFIAS, compared to their counterparts who had higher 9.99% HFIAS. A higher reduction in HFIAS is gained by the joint adoption of crop choices and conservation tillage compared to their counterparts, implying complementarity in the adoption of CSI for lowering food security risks. Compared to the effect of CSI non-adoption on HFIAS, the joint adoption of conservation tillage and irrigation practices has reduced (19) HFIAS. ATT shows that the CSI adopters have declined HFIAS, implying lower exposure to food insecurity access risks. On the other hand, the CSI non-adopters have increased HFIAS, indicating that they are highly food insecure due to lack of food access. Thus, they might have quickly resorted to food insecurity risk reduction options. Such mitigation options include a reduction in the amount, quality, duration, time, and frequency of foods consumed by the household. This reflects how prevalent the food insecurity risks would have been if adopters failed to adopt and how the non-adopters would have gained if they decided to adopt. These findings are in line with the results of (Issahaku & Abdulai, 2020b) in northern Ghana and (Amadu et al., 2020) in Malawi who indicated that the adoption of CSI has greater gain in reducing food insecurity through restoring different risk-reducing options over non-adoption.

**Table 9. Impact of a single and joint CSI adoption and non-adoption on household food consumption, food insecurity access, consumption coping strategy, and food expenditure share**

| CSI packages | Adopters (actual) | If they would not adopt | ATT | Non-adopters (Actual) | If they would adopt | ATU |
|---|---|---|---|---|---|---|
| **Food Consumption Score (HFCS)** | | | | | | |
| C1T0I0 | 57.14 | 25.32 | 31.92** | 20.60 | 49.33 | -28.73*** |
| C0T1I0 | 23.19 | 21.32 | 1.87 | 23.42 | 37.43 | -14.01 |
| C0T0I1 | 22.23 | 19.33 | 2.90 | 19.53 | 41.93 | -22.4** |

| | | | | | | |
|---|---|---|---|---|---|---|
| C1T1I0 | 65.34 | 50.43 | 14.91** | 24.95 | 19.22 | 5.73 |
| C1T0I1 | 57.34 | 18.33 | 39.01*** | 11.31 | 42.79 | -31.48*** |
| C0T1I1 | 37.21 | 27.45 | 10.76* | 32.32 | 30.11 | 2.21 |
| C1T1I1 | 30.84 | 21.21 | 9.63 | 27.41 | 42.04 | -14.63* |
| **Food Insecurity Access Score (HFIAS)** | | | | | | |
| C1T0I0 | 8.13 | 21.31 | -13.18** | 22.12 | 12.13 | 9.99*** |
| C0T1I0 | 10.21 | 24.44 | -14.23** | 23.44 | 20.49 | 2.95 |
| C0T0I1 | 7.37 | 19.22 | -11.85 | 19.73 | 10.89 | 8.84** |
| C1T1I0 | 9.21 | 26.01 | -16.81** | 9.11 | 18.6 | -9.49** |
| C1T0I1 | 17.33 | 9.21 | 8.12 | 25.28 | 23.21 | 2.07 |
| C0T1I1 | 5.11 | 24.14 | -19.03** | 18.44 | 17.01 | 1.43 |
| C1T1I1 | 11.99 | 19.44 | -7.44 | 10.95 | 9.811 | 1.139 |
| **Coping Strategy Index (CCSI)** | | | | | | |
| C1T0I0 | 52.3 | 67.44 | -15.1* | 45.45 | 32.21 | 13.24** |
| C0T1I0 | 43.11 | 55.32 | -12.2* | 52.32 | 41.48 | 10.84 |
| C0T0I1 | 32.44 | 36.33 | -3.89 | 59.21 | 30.98 | 28.23*** |
| C1T1I0 | 40.21 | 42.35 | -2.14 | 43.19 | 41.21 | 1.98 |
| C1T0I1 | 55.22 | 60.31 | -5.09 | 56.21 | 28.03 | 28.18*** |
| C0T1I1 | 56.36 | 55.22 | 1.14 | 63.1 | 43.43 | 19.67** |
| C1T1I1 | 42.11 | 68.33 | -26.2* | 43.11 | 40.81 | 2.3 |
| **Food Expenditure Share (HFES)** | | | | | | |
| C1T0I0 | 6341 | 8567 | -2226** | 5431 | 3234 | 2197** |
| C0T1I0 | 5567 | 5987 | -420 | 7987 | 4092 | 3895*** |
| C0T0I1 | 6142 | 7345 | -1203** | 6415 | 3682 | 2733** |
| C1T1I0 | 7562 | 6987 | 575* | 4498 | 4372 | 126 |
| C1T0I1 | 4421 | 7241 | -3180*** | 5719 | 3627 | 2092** |
| C0T1I1 | 5987 | 7342 | -1355 | 4618 | 4261 | 357 |
| C1T1I1 | 5528 | 8671 | -3143*** | 5987 | 4267 | 1720 |

**Note:** Each component of CSI consists of binary variables of Crop Choice (C), Conservation tillage (T) and Irrigation use (I), where the subscript 1, refers if adopted, 0 otherwise. We report actual outcome with a single and joint CSI adoption (A), counter-factual outcome without a single and joint CSI adoption scenario (C) and difference in actual outcome and counterfactual outcome as impact (ATT). We do not report standard errors to save space. ***, **, * the

difference is statistically significant at 1%, 5% and 10% probability level, respectively. Source: Sample household panel and actual climate data (1992-2022).

Table 5 presents the average treatment effects on the treated and untreated households to indicate the impact of CSI adoption on household food security. It was found that, on average, adopters of crop choice only and conservation tillage only have decreased (15) CCSI scores. ATT shows that the difference between CSI adopters if they have adopted and if they would not have adopted is statistically significant at a 1% probability level. The value of CCSI is higher (13) among farmers who do not adopt crop choice only in actual and counterfactual situations. The ATU showed a statistically significant difference at a 1% probability level. This shows that CSI adoption might have increased food insecurity requiring the use of different options to cope with the consumption failures. Similarly, the CSI non-adopters have largely failed below food security thresholds and thus opted to switch mitigation strategies to food insecurity impacts. In addition to this, on average, the joint adopters of crop choice, conservation tillage, and irrigation practices have lower (26.2) CCSI. ATT indicates that the difference is statistically significant at a 10% probability level. This is due, in part, to the fact that adopters of CSI have a greater capacity to anticipate food insecurity risks and subsequently use measures that can reduce food insecurity while building their resilience through higher food production. As a result, farmers might not have been subjected to applying additional consumption coping strategies to mitigate food insecurity. These findings are consistent with the results of(Ali et al., 2022) in the Central Rift Valley of Ethiopia and (Tambo & Wünscher, 2017) in northern parts of Ghana who indicated that that improved technology adopter households on average showed more food consumption and but less coping strategy scale.

On average, the joint adoption of crop choice and irrigation practices has reduced food expenditure share by 3180 Ethiopian Birr (ETB) and their counterpart increased by 2192 ETB. Farmers who jointly adopt crop choice, conservation tillage, and irrigation have lowered CCSI by 3143 ETB. The ATT value showed a statistically significant difference at a 1% probability level. In addition, the adoption of crop choice only has reduced food expenditure share by 2226 ETB. Contrarily, farmers who do not adopt crop choice only have increased food expenditure share by the value of 2296 ETB. The difference is statistically significant at a 1% probability level. This is also true for farmers who do (not) adopt irrigation only in both actual and counterfactual cases with a statistically significant difference at a 5% probability level. These results are because the adoption of crop choice and irrigation might have increased productivity and food availability for household consumption and reduced

additional food expenditure. These results are in line with the findings of (Makate et al., 2019) in South Africa showed that improved technology adoption has a positive and significant effect on food availability in the household for consumption. Opposing to these findings, (Wainaina et al., 2016) in Kenya indicated that the adoption of climate-smart agriculture can enhance household food consumption expenditure by improving productivity and income.

# 5. Conclusion

This study investigated factors that influence single and joint CSI adoption and how this adoption impacts household food security in Ethiopia. Results showed the importance of plot fertility and plot slopes in influencing the joint adoption of improved crop varieties, conservation tillage, and irrigation practices as well as the joint adoption of conservation tillage and irrigation practices, respectively. Findings also indicated the positive effects of household gender on the joint adoption of improved crop varieties, conservation tillage, and irrigation practices, but negative effects on the choice of improved crop varieties only. Household access to credit service is an important variable in influencing the joint adoption of improved crop varieties, conservation tillage, and irrigation practices as well as the choice of improved crop varieties only. Findings indicated the importance of social connection and farmers' levels of trust in extension agents in affecting the joint adoption of improved crop varieties and conservation tillage along with irrigation use. Membership in social groups plays a significant role in driving a single and joint adoption of improved crop varieties, conservation tillage, and irrigation practices. Farmers' perception of seasonal rainfall variability and increased drought frequency has a significant impact on the single and joint adoption of crop choice, conservation tillage, and irrigation practices. Hence, it was concluded that farmers' single and joint CSI adoption is largely affected by several policy-relevant socio-economic and climatic factors.

Findings indicated that a single and joint CSI adoption has positive effects on household food consumption scores, but negative effects on the HFIAS and CCCPI. However, the level of improvement in household food consumption greatly varies when farmers do not adopt or adopt a single CSI and combinations of CSI. Results revealed that a single CSI adoption has positive and significant gains over joint CSI adoption in terms of HFCS. This contradicts previously well-established expectations that the joint CSI adoption has higher gains over a single CSI adoption to improve food security. This is supported by the positive and significant gains for the single adoption of crop choice only and irrigation use only compared to the gains obtained from the

joint adoption of crop choice, conservation tillage, and irrigation practices. Hence, the results do not support the notion that the joint adoption of large complementary CSI often results in higher gains in food security. Based on these results, it was concluded that improvement in food security is not only driven by the type and number of CSIs jointly adopted, but rather depends on several farm, climate, and housing characteristics. This finding would not have been possible if these CSIs were examined individually without considering the joint adoption effect. In addition, the single and joint adopters of CSI have negative gains from the CSI adoption compared to the positive gains of CSI non-adoption in terms of HFIAS and CCPI. Despite this difference, the results of the study should be interpreted with caution.

Based on the results of this study, efforts towards improving soil fertility, particularly in a steeped slope through promoting conservation tillage along with diverse soil and water conservation practices should be strengthened. Given that various agroecologies have distinct farming systems and farm features, it is recommended to develop tailored approaches that account for local heterogeneity. Despite the exogenous nature of climate shocks, regional governments may play a leading role in creating special adaptation mechanisms to climate shocks such as drought and perceived seasonal rainfall variability. In this regard, promoting combinations of drought-resistant crop varieties, conservation tillage, and rum pump irrigation in the areas where households are frequently affected by droughts and facing frequent variability in seasonal rainfall is highly recommended. In addition, provision of the quality and timely information on weather change easily accessible and understandable to farmers can reduce the CSI adoption challenges including the right combinations of CSIs. The significant effects of gender on CSI adoption indicate that policymakers should integrate gender issues into CSI projects. Particular attention should be given to strengthening social connections, building farmers' trust in extension agents, and promoting membership in local organizations by enhancing their capacity to organize in adopt a single and joint CSI. Given the positive effects of the joint CSI adoption on HFCS implies the need to focus on promoting combinations of drought-tolerant crop seeds, conservation tillage, and irrigation practices that enhance household food security while reducing climate risks.

Though this study yields important findings, which are generally in line with the hypothesis, readers should bear some limitations in mind while referring to and using this paper for future studies. The result may be subject to the recalling capability and event perception of the sample households since some important variables included in this study are obtained from retrospective questions. As noted earlier, using a seven-day and 30-day recall

in HFCS and HFIAS, respectively, it was not possible to account for seasonal variation in food security driven by CSI adoption. Future research should consider seasonal variation in food security into CSI adoption and food security analysis by including more advanced indices with higher recall days. To provide a more comprehensive and detailed view of the institutional challenges related to CSI adoption, future studies should consider analyzing the current extension system where many extension agents lack adequate knowledge of CSIs for promotion. Despite these caveats, there was no expectation from the findings of any systematic bias causing over (under) estimation), which could lead to sub-optimal decisions.

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# 7. Appendices

**Appendix 1: Food groups and weights**

| S.No | Food Item (customize for local context) | | Food groups | Weight |
|---|---|---|---|---|
| 1 | Maize , maize porridge, rice, sorghum, millet pasta, bread and other cereals | | Cereals | 2 |
| 2 | Cassava, potatoes and sweet potatoes | | Tubers | 2 |
| 3 | Beans. Peas, groundnuts and cashew nuts | | Pulses | 3 |
| 4 | Vegetables and leaves | | Vegetables | 1 |
| 5 | Fruits | | Fruit | 1 |
| 6 | Beef, goat, poultry, pork, eggs and fish | | Meat and fish | 4 |
| 7 | Milk yogurt and other diary | | Milk | 4 |
| 8 | Sugar and sugar products | | Sugar | 0.5 |
| 9 | Oils, fats and butter | | Oil | 0.5 |

**Appendix 2: Justifications for weight**

| Food groups | Weight | Justification |
|---|---|---|
| Main staples | 2 | Energy dense, protein content lower and poorer quality (PER less) than legumes, micro-nutrients (bound by phytates). |
| Pulses | 3 | Energy dense, high amounts of protein but of lower quality (PER less) than meats, micro-nutrients, low fat. |
| Vegetables | 1 | Low energy, low protein, no fat, micro-nutrients |
| Fruit | 1 | Low energy, low protein, no fat, micro-nutrients |

| | | |
|---|---|---|
| Meat, poultry, fish, eggs | 4 | Highest quality protein, easily absorbable micro-nutrients (no phytates), energy dense, fat. Even when consumed in small quantities, improvements to the quality of diet are large. |
| Milk/dairies | 4 | Highest quality protein, micro-nutrients. However, milk could be consumed only in very small amounts and should then be treated as condiment and therefore re-classification in such cases is needed. |
| Sugar | 0.5 | Empty calories. Usually consumed in small quantities. |
| Oil | 0.5 | Energy dense but usually no other micro-nutrients. Usually consumed in small quantities |

# Mission

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Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
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communications@aercafrica.org