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Impacts of adaptation to climate change on farmers' food security and level of sesame production in Western Ethiopia

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Abstract

The existence of multiple stresses and poor adaptive capacity make Africa most susceptible to climate change. In Ethiopia the potential adverse effects of climate change on the agricultural sector, the main stay of the country's economy, are major concerns. To ensure food security, reducing the vulnerability of agricultural systems through different feasible adaptation strategies is one of the policy options in response to climate change impact This study is a first of its kind in examining the relative effectiveness of various adaptation strategies in ensuring farmers' food security and enhancing level of sesame production in rural area of Western Ethiopia. In addition to data obtained from meteorological stations, cross-sectional data were collected interviewing 400 farm households. Descriptive statistics, two-stage least square (2SLS) and double-hurdle (D-H) models were used to analyze the data. The results of the study indicate that households are adapting using various strategies to the looming climate change in the area. The study also indicated that, though sesame production was negatively impacted by the climate hazards, smallholders have continued its production at minimum level due mainly to its high value crop character. 2SLS estimation results revealed that rainfall and temperature variability have negative impact on household's food security. Moreover, the result indicates effectiveness of climate adaptation strategies namely agronomic practices, irrigation and soil and water conservation in reducing climatic risks and ensuring household food security. The result also implicitly indicated that farmers continued to adapt sesame production under risk climate and it is contributing to farmers' food security. Further, the result revealed that climate change adaptation strategies have positively impacted the level of sesame production. Consequently, policy that augments households' climate awareness and promotes adaptation decision and strategies could help reducing risks pertaining to climate and thereby improves farmers' food security status and production of high value export potential crop—sesame.

Keywords Climate change, Adaptation, Impact, Food security, Sesame, Two-stage least square, Double-hurdle model, Western Ethiopia

Introduction

Climate change has become increasingly recognized as a global phenomenon with potentially far-reaching implications [37, 38, 40, 49] and higher impact on developing countries [39, 47]. This is expected to have negative impacts on agriculture in many regions through the greater frequency and intensity of extreme weather events such as droughts and floods [36, 41]. It has also led to widespread adverse impacts on food and

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water security, human health and on economies and society and related losses and damages to nature and people (high confidence) [27, 41]. Africa, according to IPCC [37], is mostly susceptible to climate change due to the fact that the continent is under multiple stresses and of poor adaptive capacity. This indicates vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (high confidence) [41]. Thus, climate action at global, regional, national and local levels across agri-food systems is fundamental to their transformation in a coherent manner according to, and dependent on, national contexts and capacities, including for the pursuit of other environmental, social and economic objectives [27].

Although overall agricultural productivity has increased, climate change has slowed this growth in agricultural productivity over the past 50 years globally (medium confidence) [40, 41]. Climate change has reduced food security and affected water security due to warming, changing precipitation patterns, and greater frequency and intensity of climatic extremes, thereby hindering efforts to meet Sustainable Development Goals (high confidence) [40, 41]. Increasing weather and climate extreme events have exposed millions of people to acute food insecurity and reduced water security, with the largest impacts observed in many locations and/or communities in Africa and for small-scale food producers, low-income households and Indigenous Peoples globally (high confidence) [41]. With the estimated number of people facing hunger rising to 720–811 million in 2020 [26] and the already tangible impacts of climate change and extreme weather events on food security, nutrition and poverty, the urgency to address climate change has significantly increased [27].

Many authors have explored the impact of climate change on food security in sub-Saharan Africa using either agronomic model or Ricardian analysis [18, 51, 52]. Historically, it has been noted that extreme climate events such as drought and floods reduced one-third of Ethiopia's economic growth [58]. Recent findings indicate Ethiopia is one of the most vulnerable countries to climate variability and climate change due to its high dependence on rain-fed agriculture and natural resources, and relatively low adaptive capacity to deal with these expected changes [11]. The country is exposed to numerous hazards including droughts, floods, volcanoes, and earthquakes. Projected trends indicate that through the end of the century there is a likely 20% increase in extreme high rainfall events [11]. Estimates suggest climate change may reduce Ethiopia's GDP up to 10% by 2045, largely through drought-induced impacts on agricultural productivity [54].

For Ethiopia the potential adverse effects of climate change on the agricultural sector, the main stay of the country's economy, are major concerns. The country is highly vulnerable due to in general low adaptive capacity of rural households and exposure to natural and anthropogenic threats [11, 17, 59]. Recently, the deadliest El-Nino episodes, a warming of the ocean surface in the central and eastern tropical Pacific Ocean, ever recorded in history has left the country in devastation. It plunged into limited agricultural production, straining livelihoods and exacerbating food insecurity among poor and vulnerable households [25]. This El-Nino plug forced an estimated 10.2 million people to fall under food assistance in 2016 and over one-third of the country's districts facing food security and nutrition crisis [25].

A large body of literature has recognized adaptation as one of the policy options in response to climate change impact. [36] defined adaptation to climate change as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Reducing the vulnerability of agricultural systems to climate change through different adaptation mechanism is thus an important priority for agricultural development and to protect and improve the livelihoods of the poor and to ensure food security [27, 41, 56].

Studies reveal that without adaptation strategies, climate change is generally detrimental to agriculture, but can partly be offset by various adaptation measures at the farm level [48]. To harness climate posed difficulties, many potential adaptation options have been suggested for developing countries. For instance, soil and water conservation practices have been suggested in response to soil erosion problem posed by climate [43]. Similarly, the use of different agronomic practices such as drought-tolerant crop varieties, crop diversification, and improved crop varieties is considered as the potential adaptation option to the adverse effects of climate change on agriculture [24]. Moreover, studies showed the importance of adoption livelihood diversification and small-scale irrigation schemes to overcome the impact of the unreliable and erratic pattern of rainfall and repeated drought [6]. The degree to which the agricultural sector is affected by climate change depends on the adaptive capacity of the farming communities [6].

Empirical literatures show that, in Ethiopia, efforts have been made to assess the climate change impact on agriculture and identified the existing adaptation options in response to its adverse effect [1, 3, 8, 9, 30, 31]. These studies are of great importance in revealing the extent of the climate impact and recommending different adaptation options [33, 35]. These days, however, despite the increasing promotion and use of different adaptation strategies, there have been limited empirical studies that attempted to analyze its impacts on household food security. Ali and Erenstein [5] showed that farmers adopting more adaptation practices had higher food security levels than those who did not. Likewise, it is found that the adoption of climate-smart agricultural practice has positive and significant impacts on the objective measure of food security, but no impact is observed for the subjective food security indicator [9]. Moreover, the analysis by Gebrehiwot and Anne Van Der [32], using food security package program that has been implemented as an adaptation option to changing climate showed that the program has had a significant effect on improving household food calorie intake.

To the best of our knowledge, Ali and Erenstein [5], Asfaw et al. [9], Gebrehiwot and Van Der Veen [32] and Di Falco et al. [20, 21] are the only studies that attempt to measure the impact of adaptation on food security. While these impact studies provide valuable information, they are more focused on how the changing climate is likely to affect yields and crop production. Moreover, the results from these studies are highly fragmented, and inadequate to address local context and different dimensions of household food security. For instance, study by Di Falco et al. [20, 21] which focus only on agricultural productivity provides a partial assessment of food security–adaptation relationship. However, none of these studies have examined the relative impact of different adaptation options in response to climate change on food security. Similarly, we have found no study that deals with the impact of different adaptation strategies specifically on sesame crop production. Sesame is one of the major oilseeds for which Ethiopia is known in the international market. It represents, on average, 32 percent of the total cultivated area under oilseed production for the period 2005–2012 [15]. In 2014, sesame production was dominated by more than 867, 347 small-scale farmers cultivating a total of 420,495 hectares of land in Ethiopia. The total production of sesame was 440 million tons in 2013 [16]. Although there was an increase in average yields from 2000 to 2012 [28], they are still considered low compared to the full potential sesame production. Though sesame is well-adapted to Ethiopia's climate, it is also sensitive to weather hazards and exposed to the impact of the looming climate change and variability [42, 55]. The investigation on how farmers' adaptation measures in response climate change affects household food security and level of sesame production in the study locality is relevant because most of the debate on the effect of climate change in agriculture has been focusing on the impact of climate change rather than on the role of adaptation.

To fill this gap in literature, our current study intended to provide a comprehensive analysis on the impact of adaptation options to climate change in Western Ethiopia. The specific objective of the paper was, therefore, to estimate the effect of adoption of agronomic practices, livelihood diversification, soil and water conservation (SWC) measures, and small-scale irrigation strategies as climate change adaptation options on household food security status. Additionally, we have also analyzed how these adaptation measures have impacted the level of sesame production. This has been measured by household food insecurity assess scale, using two-stage least square model and truncated regression model. The study provides empirical evidence on the potential benefit that adaptation generate to improve household food security, and this information helps policy makers to give emphasis on adaptations in the process of policy design. Moreover, the study also tries to highlight how sesame production is related to climate change adaptation options and its role in enhancing smallholders' food security status.

Methodology

Description of the study area

This study was undertaken in East Wellega Zone, Ethiopia. The study area is geographically located between 9° 31 9"North latitude and 36° 45′ 27″ E longitude. According to Ethiopian Statistical service July 2023 report[1] the zone has a total population of 1,847,649 (918,529 male and 929,120 female) with an area of 12,579.77 square kilometers and a population density of 96.46 people per square kilometers (CSA 2007). Among the 18 districts in the zone and Gida Ayana and Sasiga districts were selected for this study (Fig. 1). According to data from the district Rural and Agricultural Development Office, Sasiga district has a total population of 80,814. The district had 11.9 percent arable or cultivable land, 2.8 percent pasture land, 1.6 percent forests, and the remaining 83.7 percent were swampy, marshy, or otherwise unusable. Gida Ayana district has a total population of about 142,408. 65.7 percent of the land was arable or cultivable, 22.8 percent were pastureland, 8.7 percent were forests, while the remaining 2.8 percent were unusable. Sesame and khat are two important cash crops and main sources of income in the district.

Data and methods of data collection

Secondary data regarding annual temperature and rainfall from the year 1989 to 2017 were obtained from the three metrology stations found in the sampled districts namely Anger station for the Gida Ayana district and

[1] Population-of-Zones-and-Weredas-Projected-as-of-July-2023.pdf (statsethiopia.gov.et).

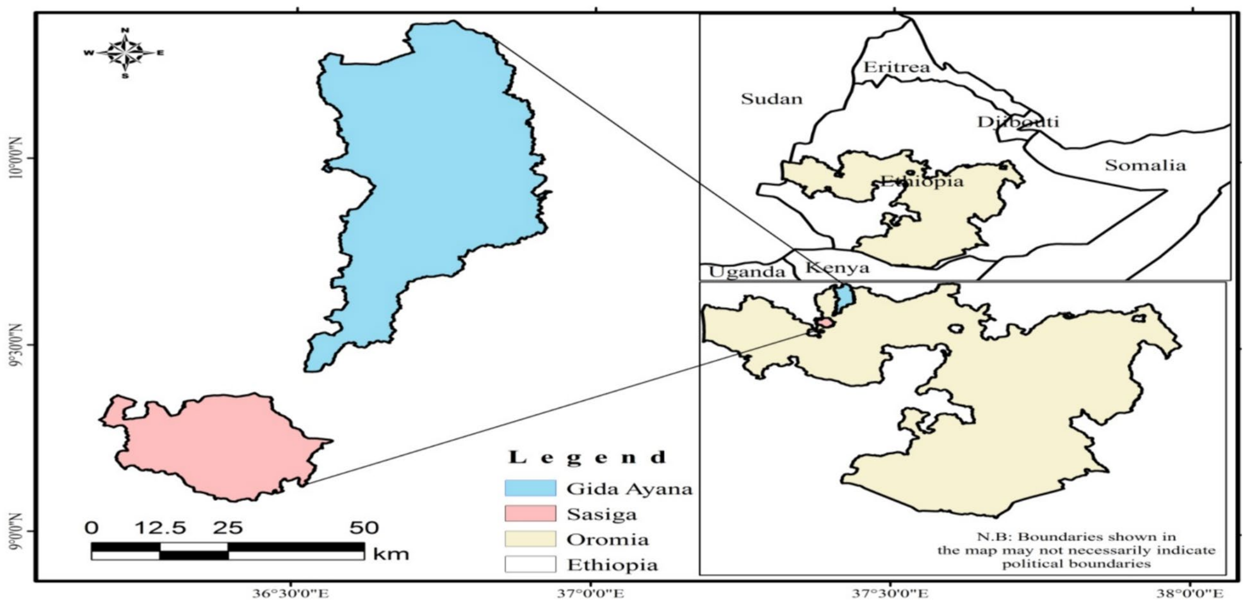

Fig. 1 Location of the study area in Oromia regional state

Sasiga and Ehud Gebiya stations for the Sasiga district. Primarily data were generated by a cross-sectional survey during the 2017 production season. Both closed- and open-ended semi-structured questionnaires were deployed to gather data on status and determinants of food security. We also conducted key informant interviews to collect more information on key related issues. Additionally, focus-group discussions (FGDs) were also held with selected sesame-producing farmers to obtain additional necessary data.

Sampling procedure

To secure representative sample, we followed a three-stage sampling technique. Frist, two districts Gida Ayana and Sasiga, were purposively selected from the top five sesame growing districts of the zones. Then, using a simple random sampling we choice 50 percent of the total sesame growing kebeles (lower administrative unit) from each of the two selected districts. Accordingly, a total of ten kebeles, five kebeles form each district were randomly selected. Finally, 400 farm households were randomly selected. The total sample was proportionally distributed among the different sample kebeles.

Methods of data analysis

General theoretical framework

Sustainable livelihood framework (SLF) was adopted as one of the main theoretical underpinnings to lead the analysis of smallholder exposure and adaptation to climate change and its proceeding impact. This framework is very helpful to comprehend the link among livelihood climate exposure during crop production, their adaptation strategies and impact on food security and sesame production. The SLF consists of five blocks: the vulnerability context; livelihood assets; policy, institutions and procedures; livelihood strategies; and its outcomes. In this study, we refer to vulnerability or exposure as the climate change and its associated variability- rainfall shock and rising temperature. It largely impacts the accumulation of household assets as it directly affects livelihood strategies, institutional process and living outcomes of a society [13, 14].

As a main framework, this study used SLF because it is an essential device that enables us to grasp the linkage in between exposure to climate change, adaptation alternatives, sesame production and food security in a systematic and holistic ways. It provides a framework for analyzing adaptation options and livelihood assets that determine vulnerability of production and food security and the specific variables that affects those [22]. The inter-relations among vulnerability context, livelihood assets; institutions and organizations that shape or constrains both livelihood assets and adaptation options that farmers used; and the livelihood outcomes resulted from this process and its impact on livelihood assets are portrayed in Fig. 2 below.

Empirical models specification

Household food security model: is an empirical model that was estimated to analyze effects of socioeconomic variables, climate and adaptation strategies on household food security. Household's food security is modeled as a

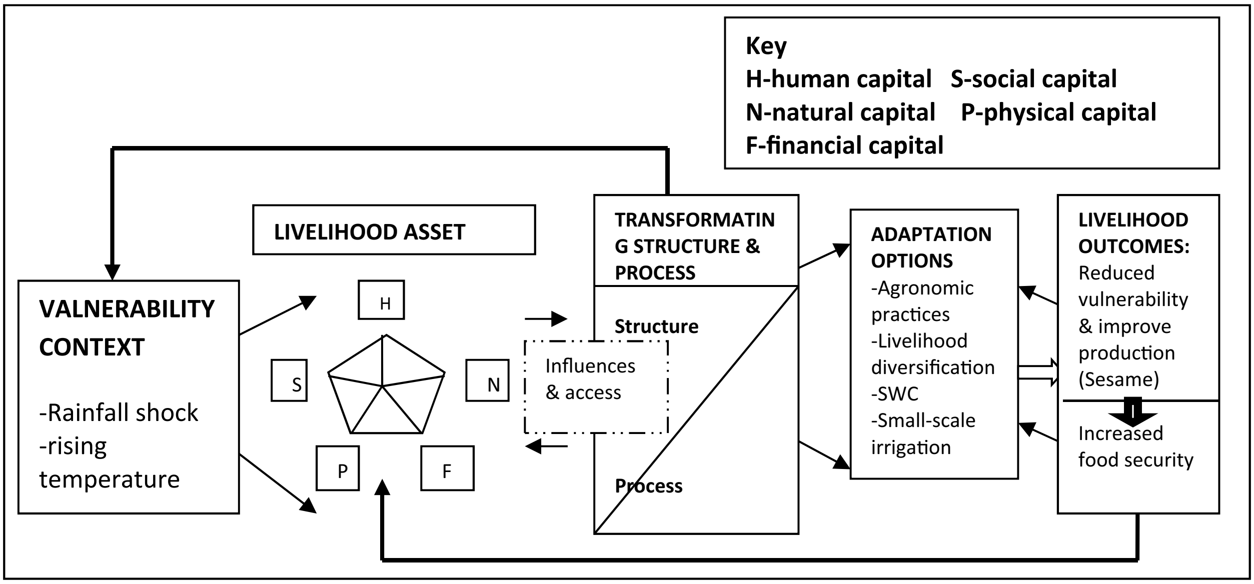

Fig. 2 Sustainable livelihood frameworks. Source: Adopted from [13, 14, 22], with own modification

function of multiple socioeconomic and climatic factors. For this purpose, food security index constructed based on Household Food Insecurity Scale HFIAS was used as a dependent variable. Different studies have used similar approaches in estimating food security index (Jennifer et al. 2007; Kobal et al. 2019; Mota 2019).

In order to examine the effectiveness of climate adaptations in helping households ensure food security, four dominant strategies were selected. Dummy variables assuming value one if a household employs a given method and zero otherwise was created. These adaptation dummies were included in the food security model separately per se and not as a package. This was because household's decisions regarding different adaptation strategies were assumed to be independent. Separate inclusion of each adaptation in food security model was important to identify most effective strategy.

However, household's decision to use climate adaptation strategies can be affected by unobserved individual heterogeneity such as farmers' skills or ability to learn and adopt new technologies. In turn, unobserved heterogeneity would result in the endogeneity problem where some of the explanatory variables may be correlated with the error term of regression model. Therefore, the endogeneity of adaptation variables was checked before empirical analysis of food security model using Durbin–Wu–Hausman test. Test results showed that adaptation decisions were endogenous which would result in biased and inconsistent estimation of food security model parameters. This can lead to the failure of measuring true effects of adaptation strategies. Therefore, controlling for endogeneity problem was an appropriate task to obtain consistent estimates. In this regard, using 2SLS estimation framework would help obtain robust estimates because it controls for endogeneity bias.

Consequently, 2SLS estimation framework was employed to estimate food security model. Following Angrist and Krueger [7], predicted values of endogenous adaptation dummy variables were used as an instrument. This approach of using predicted values as an instrument was employed in previous studies by Abera et al. [2] and Di Falco et al. [21]. The standard requirement for the instrumental variables' appropriateness was that instruments should not be correlated with the error term in structural equation but instead be correlated with the endogenous variables. In this case, excluded instrument should not be correlated with farmers' unobservable individual skills. Instead, they should be correlated with farmers' decision concerning climate change adaptations. In this study, we used four instrumental variables (access to agricultural extension services, market access, access to climate information and cooperative memberships) in getting the predicted values of the endogenous adaptation strategy variables (agronomic practices, livelihood diversifications, soil and water conservations and small-scale irrigations), respectively. In addition to statistical test, the selection of those instruments was guided by previous empirical literature [10, 19, 34, 53].

To test instrument relevance, F-test of overall significance of excluded instruments was used. Finally, a multivariate econometric model was specified as follows:

$$HFIAS_i = f(H, L, S, LO, I, SRI, T, D_i), \quad (1)$$

where $HFIAS_i$ = household's food insecurity access index calculated using nine indicators to access the status household food security. H = vector of household characteristics such as age, sex and education of household head, and household size, L = total amount of labor hours spent per hectare of cultivated land. S = size of the cultivated land held by household measured in hectares, LO = household's livestock ownership in total livestock unit (TLU), I = total amount of non-farm income earned by the household, SRI = subjective observed rainfall satisfaction index used as a measure of rainfall variability. T = household specific temperature variable proxied by altitude. Di = dummy variables for each typical adaptation strategies used by each farm household.

Before executing regression analyses, multicollinearity problem among the explanatory variables was checked using variance inflating factor (VIF) for continuous variables and contingency coefficient (CC) for discrete variables. Results of VIF which was less than 10 and CC less than 0.75 imply no serious multicollinearity problem among the variables. Besides, the problem of heteroskedasticity was tested using standard Breusch–Pagan/Cook–Weisberg test for heteroskedasticity. Resulting P-value of 0.98 indicates that the null hypothesis of homoscedasticity among the explanatory variables included in both models cannot be rejected.

Double-hurdle (D-H) model

This was the second empirical model estimated to analyze impact of climate adaptation strategies, socioeconomic variables and institutional factors on the level of sesame production. The recommended model to capture this is the double-hurdle (D-H) model which assumes farmers faced with two hurdles in any agricultural decision-making processes (Cragg 1997; Sanchez 2005; Humphreys 2010). The first is either to participate in a given activity or not and the second decision become he level/intensity of participation in an activity (which level of sesame production in this study). We choose D-H model due to its capacity to allow us for the distinction between the determinants of production participation and the level of participation in sesame production through two separate stages. The model estimation involves two step regressions. First, is running a probit regression to identify factors affecting the decision to participate in the activity using all sample population. Secondly, a truncated regression model on the participating households to analyze the level of participation runs. Once farmers decision to participate in sesame production is confirmed by probit regression, the focus of this study is to capture the impact of climate changes on the level of sesame production through truncated regression.

In order to estimate the likelihood function, we start from the first stage (production decision) to identify whether the households are producers or not, using probit analysis. Thus, let Pi denote a binary indicator function taking value "1" if farmers participate in sesame production in 2017 production year and "0" otherwise. Further, let Li denote the land allocated to sesame produced in the specified production year. Then the likelihood function for the standard double-hurdle model can be written as:

$$ln\,L = \sum_{G1=1} ln\left[\varphi(\chi_1\gamma) \times \left(\frac{1}{\sigma_u}\right) \times \phi\left(\frac{Y-\chi_2\beta}{\sigma_u}\right)\right] + \sum_{G2=1} ln\left[\varphi\left(\frac{\chi_2\beta}{\sigma_u}\right) \times (1-\phi(\chi_1\gamma))\right] + \sum_{G3=1} ln\left[1-\varphi\left(\frac{\chi_2\beta}{\sigma_u}\right)\right], \quad (2)$$

where ϕ and φ are the probability density and cumulative distribution function of the standard normal variable, respectively; G1, G2, and G3 are indicator functions showing whether a given observation belongs to group one, two, or three, respectively: households producing sesame, households wanting to produce but reporting zero production, and households choosing not to produce. Equation (2) can be estimated using maximum likelihood (ML) techniques, which will give consistent estimates of the parameters. If u_i and e_i are independent, the ML function can be separated into a probit and a truncated normal regression model.

Accordingly, we examined factors affecting the level of sesame production, conditional on participation decision, which was implemented using the truncated regression analysis. Thus, it involves the truncated regression that can be specified as:

$$L = L^* \text{ if } L^* > 0 \text{ and } L = 0 \text{ otherwise.}$$

From this, we can specify the reduced form of the truncation model as:

$$L = \beta_0 + \beta_i Z_i + \upsilon_i, \quad (3)$$

where L is the size of land allocated to sesame production in hectare, L^* is the latent variable which indicates the land size is greater than zero, β_i is the vector of parameters to be estimated, Z_i is the vector of exogenous

Table 1 Association between determinants (discrete variables) of sesame production decisions

Variables	Categories	Producers (n)	Non-producers (n)	Chi-square value
Sex	Female	24	5	22.14***
Credit access	Yes	153	46	8.34***
Coop membership	Yes	189	65	5.76***
Farm extension	Yes	173	62	3.09*
Income nonfarm	Yes	60	35	2.99*
Food availability	Yes	251	66	10.43**
Access price info	Yes	195	76	1.17 ns
Selling channels	Via brokers	150	99	31.76*

***, **, * and ns represents significant at 1%, 5%, 10% and not significant, respectively

Table 2 Association between determinants (continuous variables) of sesame production decision

	Producers		Non-producers		
	Mean	SD	Mean	SD	t-value
Age	41.54	12.09	41.31	10.38	0.19 ns
Education	4.56	3.58	4.01	3.57	3.39***
Active family labor (AE)	9.21	3.68	4.89	4.24	10.31***
Numbers of Oxen	2.10	1.53	1.81	1.58	1.76*
Land total	4.41	2.96	3.21	2.52	3.86***
Year sesame	10.93	7.39	11.44	8.50	– 0.59 ns
Income livestock	7.24	8.03	6.85	8.12	2.45**
Distance extension	2.29	4.25	2.23	2.93	0.13 ns
Distance market	2.51	2.09	2.32	2.05	0.61 ns

***, **, * and ns represents significant at 1%, 5%, 10% and not significant, respectively

explanatory variables and υ_i is the error term. The empirical model used in this study assumes that the total hectares of land allocated for sesame production was a linear function of continuous and dummy explanatory variables and was specified as follows:

$$L = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_{14} X_{14i} + \upsilon_i, \qquad (4)$$

where L was the size of land allocated to sesame production in hectare in 2017 production year, β_is—are the coefficients to be estimated and υ_i is the error term. The list of X_{1i} to X_{14i} includes adaptation strategies, household characteristics, socio-economical, institutional and climatic factors.

Results and discussion

Characteristics of respondents

Tables 1 and 2 below present the summary statistics for dummy and continuous variables. Descriptive statistics of the respondent indicates about 93 percent were male-headed households. On average, the sample respondents had been engaged in farming for 11 years and about 23 percent of the sample household heads did not have formal schooling. The mean family size of the sample households measured in adult equivalence (AE)[2] was 7.10. On average, respondents owned 1.96 oxen and they owned 4.26 units of livestock measured in TLUs which are equivalent to 0.81 TLU per adult equivalent. The total size of the land owned by the sample respondents ranged from 0.25 to 24 hectares while the average size was 3.81 hectares. Nearly half the total respondents had access to any form of credit, 66 percent of them had cooperative membership, and 24 percent were engaged in off-farm activities. Sixty percent of the respondents had access to food for the whole year and 59 percent of them had access to farm extension services.

Climate change and farmers adaptation practices in the study area

The mean annual temperature and rainfall records over the period under consideration were computed from the daily temperature and rainfall records obtained from each metrology station. Figure 3 presents the 30-year trend in the annual maximum temperature data from the year 1989 to 2017. Mean annual temperature was highly fluctuating and shows rising trend after 2013 in both districts. Similarly, Fig. 4 illustrates the trend in the annual precipitation in the selected stations.

The rainfall trend indicates high variability and general decline in rainfall values over the study area. In Gida Ayana district, the result revealed a sharp decline in rainfall values from 1998 to 2001 and from 2012 to 2014. The result further shows that a noticeable decline in rainfall was observed from 2013 to 2016 in Sasiga district. Such variability was perceived to be the main cause of decline in crop production and productivity due to insufficient rainfall during the production seasons in the study area.

In response to climate change and variability, sample farmer households were asked questions about what

[2] AE and TLU are calculated using the standard conversion factor given by Storck et al. [50].

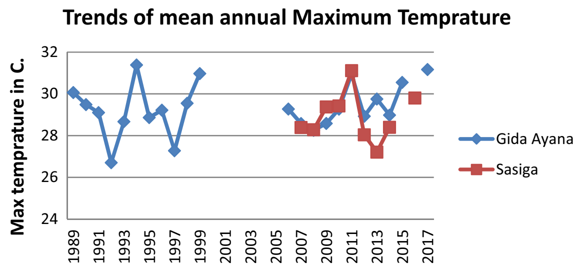

Fig. 3 Annual maximum temperature in sampled districts, 1989–2017. (There is discontinuity in temperature trend due to missing data Gida Ayana metrology stations and record was started for both temperature and rainfall in Sasiga districts only in 2006). Source: East Wellega Zone Meterology Stations 2018

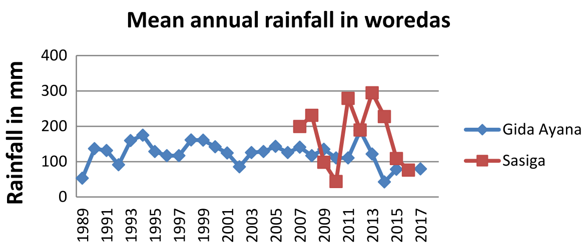

Fig. 4 Annual rainfall in sampled districts, 1989–2017. Source: East Wellega Zone Meterology Stations 2018

measures and practices they have typically used in order to cope with the negative impact of climate variability and changes. The results show that adaptation strategies farmers used include using stone bund; check dam; terrace; small-scale irrigation; drought-tolerant and/or improved crop varieties; crop diversification; and off-farm activity. For the convenience of model analysis, the identified adaptation strategies are combined into five categories including the 'no adaptation' category. Use of drought-tolerant crop varieties, crop diversification, and improved crop varieties has merged together and categorized as an agronomic practice. Likewise, use of off-farm activities is merged together into livelihood diversification component. Also, stone bund, check dam, and terrace are grouped into soil and water conservation measure.

Agronomic practice measures (36.25%) and livelihood diversifications (26.50%) are the two most widely used adaptation strategies in the study area (see Fig. 5). To minimize the risk from the total loss of crop production and to increase crop productivity, farmers employed diversifying crops grown on the same plot of farm, drought-tolerant crop variety, and improved crop variety. It is also indicated that smallholder farmers have been diversifying their sources of livelihood with an understanding of more diversified livelihood strategies lead them both enhance incomes and spread the risk for smallholder farmers (Fig. 5).

It is also found that because of the unreliable and erratic pattern of rainfall and repeated drought, about 21% of the farmers started implementing SWC. Farmers also employed small-scale irrigation schemes (12.75%) over their farm as another important strategy in their efforts to adapt to the effects of climate change. On the other hand, the number of farmers who did not adjust their farming practices in response to climate change was found to be small (3.50%). They mentioned shortage of sufficient financial resources, lack of climate-related information and shortage of land as main reasons for not adopting.

Impact of climate change adaptation on food security

In this study, households' food security was expected to be influenced by multidimensional factors and modeled as a function of multiple socioeconomic and climatic factors. About 11 explanatory variables are included in the

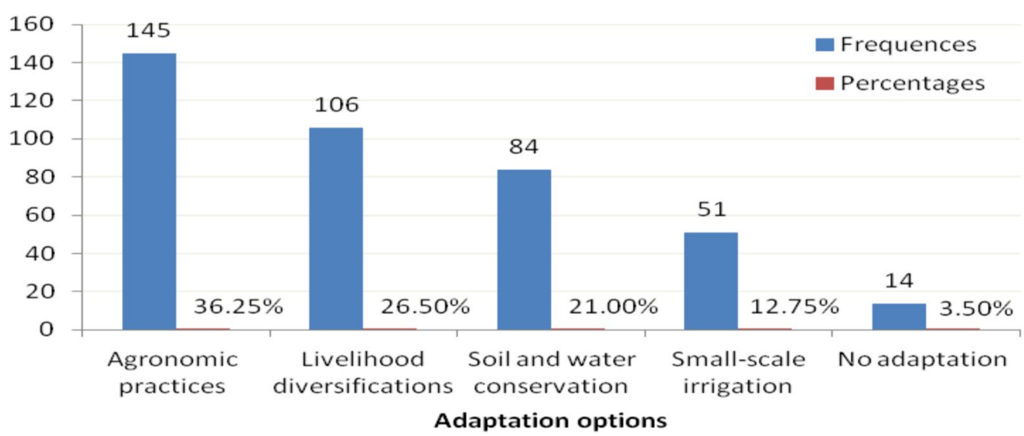

Fig. 5 Adaptation strategies used by smallholder farmers

regression model as possible determinants of household's food security. Before the estimation of model parameters, endogeneity of climate adaptation variables was tested using Durbin–Wu–Hausman test. The results showed that we can reject the null hypothesis of exogenous adaptation decisions implying endogenous nature of adaptation variables.

Moreover, weak instrument test of just-identified model was tested using robust F-test. The result reveals that there were no weak instruments since the F-value of 72.33 was by far greater than 10 (see Table 3 above). Hence, the instrumental variables were highly correlated with their endogenous variable counter parts indicating the validity of the instruments. The test results indicated that the coefficients obtained from 2SLS regression analysis can be interpreted meaningfully (Table 4).

Table 3 Results of endogeneity and weak instrument-just identification tests

Test	Score	P-value
Test of endogeneity (H0: variables are exogenous)		
Durbin Chi2(4)	10.1716	0.0039
Wu–Hausman F(4, 387)	10.1213	0.0044
Weak instrument test of just-identified model		
Robust F(4, 388)	72.3336	0.0000

Study shows a strong and inverse correlation between altitude and temperature, the more the altitude the lower the temperature pattern would be [12, 45]. The parameter estimates for altitude which was a temperature proxy variable is positive under agronomic practices, livelihood diversifications and irrigation adaptation scenarios. From the negative relationship between altitude and temperature, and positive effect of altitude on food security, we can deduce that temperature has a negative impact on household food security. More specifically, one unit change in temperature can lead to 3.34, 8.25 and 1.23 percent deterioration of household's food security position under stated adaptation scenarios, respectively. This negative impact of temperature on food security is consistent with the findings of previous studies such as Deressa and Hassan [18], Di Falco et al. [21] and Myers et al. [44].

Favorable rainfall condition has positive and statistically significant impact on food security. It significantly improves household's food security position by 39.11% under agronomic practices and 27.85% under small-scale irrigation scenarios (see Table 4). Significant impact of rainfall variability on household food security is reasonable in Ethiopian agricultural setup where production is highly dependent on natural rainfall. This result is consistent with the finding of previous studies like Abera et al. [2] and Alemayehu and Bewket [4] in Ethiopia.

Table 4 2SLS estimation results of climate change adaptation impact on food security

	Agronomic practices	Livelihood diversifications	Soil and Water conservations	Small-scale Irrigation
Dependent Variable: Food Security-HFIAS				
Explanatory Variables				
Adaptation	0.3182**(0.1642)	– 0.1324(0.1700)	0.2672**(0.1375)	0.3121*(0.1766)
Rainfall Variability	0.3911***(0.0624)	0.0765*(0.0449)	0.2529***(0.0626)	0.2672***(0.0712)
Altitude	0.0334***(0.0131)	0.0825***(0.0111)	0.0086(0.0062)	0.0101(0.0063)
Education	0.0035(0.0048)	0.0167***(0.0057)	0.0209***(0.0065)	0.0211***(0.0066)
Farm size	0.0126***(0.0067)	0.0076(0.0083)	0.0125*(0.0076)	0.0117*(0.0073)
Family size	0.0047(0.0067)	0.0029(0.0083)	– 0.0272***(0.0088)	– 0.0269***(0.009)
Livestock TLU	0.0099(0.0065)	0.0169**(0.0082)	0.0198**(0.0093)	0.0191**(0.0084)
Age of the HHH	– 0.0028*(0.0015)	– 0.0005(0.0020)	0.0017(0.0021)	0.0018(0.0022)
Sex of the HHH	– 0.0041(0.0507)	– 0.0407(0.486)	– 0.0525(0.690)	– 0.0350(0.0762)
Non-farm Income	0.0001(0.0002)	0.0001(0.0003)	– 0.0001(0.0003)	– 0.0001(0.0003)
Daily labor hours	– 0.0007(0.0063)	0.0040(0.0079)	0.0036(0.0085)	0.0034(0.0085)
Constant	– 0.3275(0.2121)	– 0.9525(0.2587)	0.2788(0.2118)	0.2198(0.2365)
Number of Observations	400			
Wald Chi2(11)	510.21	194.59	71.93	71.45
Prob. > Chi2	0.0000	0.0000	0.0000	0.0000

*, ** and *** indicate statistical significance at the probability levels of 10, 5 and 1 percent, respectively. Figures in the parentheses are standard errors, HHH is Household and TLU is Total Livestock Unit

Furthermore, results showed that climate adaptations have positive impact on household food security. Households who adopt agronomic practices, irrigation and soil and water conservation strategies were found to be more food security position as compared with those who do not adopt the strategies (see Table 4). For instance, adaptation of agronomic practice improves food security status by about 32% while SWC improved it by nearly 27%. Therefore, adaptation strategies such as crop diversification, use of modern varieties, irrigation and soil and water conservation strategies were effective in reducing risks pertaining to climate change and variability thereby helping households ensure food security. Unexpectedly, however, the coefficient of livelihood diversification is found negative and statistically insignificant.

Among the other variables, age of household and household size were found to have significant negative impact on household food security. Older household may face the challenge of productivity and efficiency loss which will result in high probability of being food insecure [23, 46]. Households with large size and more dependent family members were also more food insecure. These households need more resources, beyond what they produce, to fulfill their food needs. Negative impact of household size on food security is consistent with the finding of [23, 46, 60] and in contrast with the study by Abera et al. [2] and Faustine [29]. Level of education attained by household head was found to be positively related with household's food security position. A study by Deressa and Hassan [18] also found similar positive and significant impact. As expected, production input such as size of cultivated land held by the household are found to have a positive and highly significant impact on household's food security. This is consistent with the results of [23] and Faustine [29]. Furthermore, in line with prior expectation, household wealth indicators such as livestock ownership have positive impact on household food security. This result is consistent with the findings of Abera et al. [2].

Impact of climate change adaptation on sesame production

This study has tried to examine how sesame production is performing under the changing and variable climate in the study area. Does the changing climate have brought opportunity or threat to sesame production? Were the sesame producers adopting sesame as an adaption option crop to climate change or were they giving up its production by opting for other crops? Additionally, we analyze the impact of the climate change adaptation strategies on the level of sesame production.

The study revealed that, in response to climate change, one of the main adaptation strategies sesame producers' practices were agronomic practices. 36.25 percent of small holder typically adopted agronomic practices which encompass crop diversification, varying planting and harvesting dates, using drought-tolerant and improved seeds. The sampled farmers were asked to list the five top crops they adopted in their crop diversification strategy response to the climate change. The result indicated that large number of farmers adopted Groundnut and Sesame crops as a response to climate change adaptation strategy. More than half (56.75%) of the smallholders adopted Groundnut while nearly half (42.50%) of them adopted Sesame as a main crop diversification practice in adjustment to climate change. Specifically, farmers were asked if they adopt sesame as a diversification crop in response to the climate change and 41% of them responded positively.

On the other hand, the farmers were asked how they observed the trends sesame production over the last decades. Accordingly, nearly all smallholders (93%) revealed that the amount of sesame production over the last 10 years is declining. This was consistent with the declining national sesame production trends. The national data, according to CSA indicated that over 2010–2016 periods average production growth rate declines by -35 percent [28].

The farmers also identified the main reasons to be directly related to the climate change and variability. 64.18% of the farmers mentioned climate factors (no enough rain, heavy rain, off-season rain and biotic diseases) as the main factor for the continuously declining amount of sesame production in the study area (see Table 5). This is in line with Oxfam study that showed that the sensitivity of sesame plant to weather hazards

Table 5 Crop diversification and trends of sesame production

In response to climate change, list the main crops you adopt to diversify your agricultural production	Main crops	%	What is the pattern of the amount of sesame production over the last 10 years?		Main reasons	%
	Maize	11.25			Not enough rain	3.25
	Sorghum	12		Declining (93%)	Heavy rain	19.75
	Groundnut	56.75			Off-season rain	26.50
	Sesame	42.50			Diseases	58
	Others	32.25			Low price	33
					Others	27

[42]. Similarly, Sorsa, 2009 found that drought/inadequacy of rain as the most important sesame production problem.

Thus, if closely observed, one may see a paradox in the above results. If 93% percent of farmers said sesame production was declining due to largely (64.18%) climate factors, then how nearly half percent (42.50%) of them adopted sesame as a main crop diversification practice in adjustment to climate change (see Table 5 above)? To put it differently, how climate sensitive crop was adopted by nearly half of the farmers as an adaptation response to the climate change? We tried to grasp justification for this from FGDs carried out with different stakeholders. The result revealed that, though, sesame is climate sensitive crop the farmers have not been giving up on it due to the fact that it is a high value crop. It was observed that, while few abandoned it, large number of farmers keep sesame production but at a minimum level of production. If the production is successful, they know that they will get high return from sesame sell due to its high market value. This indicated the risk-averse behavior of the farmers let them to reduce the amount of sesame production while the high value crop character of sesame holds them back from totally avoiding its production.

Further, we employed a truncated model to identify potential explanatory variables affecting household's level sesame production captured via size of land allocated to sesame production. Table 6 below presents both the parameter estimates and average marginal effect.

The results indicated that adopting climate adaptation measures have positive impact on level of sesame production. Adoption of agronomic practices, livelihood diversification and soil and water conservation strategies have improved the level of sesame production (see Table 6). Households who adopt agronomic practices like crop diversification, using drought-tolerant and modern varieties brings 0.17 hectare more land in to sesame production. Since the households may adopt sesame as a drought-resistant crop and may also use its improved varieties this would improve the whole level of sesame production. The study result indicated that 42.50% of households adopted sesame as a main crop diversification practice in adjustment to climate change (see Table 3 above). Another study also shows farmers adoption of sesame due to its drought and high thermal tolerance characteristics [55].

Besides, livelihood diversification from farm to non-farm activities influenced level of sesame production positively and significantly. Contrary to our result, Wondimagegn et al. [57] indicated that off-farm income source negatively impacted farmers' farm involvement. However, in the case of sesame production non-farm income source has positive influence possibly due to the high value crop character of sesame that the farmers may not abandon it easily. As expected, adoption of soil and water conservation has a significant ($p < 0.05$) impact on the amount of sesame production where households who adapt this adaptation measure has 0.19-hectare additional land allocated sesame production. This is due to the fact that soil and water conservation measures help mitigate flooding, soil erosion and conserve the little rain which in turn improves crop production. Studies revealed that, if the rain is over, floods are the largest climate threat to sesame: they have potential to decrease stocks for export, severely limiting the sesame value chain [42, 55]. This indicates that soil and water conservation adaptation strategy is very essential in boosting level of sesame production by curbing flooding and soil erosions. Among the other variables, sex of household, education, farm size, credit and food availability were found to have significant positive impact on the level of sesame productions.

Table 6 Truncated regression of determinants of intensity of sesame production

Land sesame	Coef	St.Err	Marginal effects	Z-value
Agronomic practices	0.7951	0.4988	0.1707	1.68*
Livelihood diversification	0.8612	0.5367	0.1849	1.70*
Soil and water conservation	0.8996	0.4899	0.1932	1.94**
Small-scale irrigation	1.2336	0.8614	0.2649	1.51
Sex	2.1116	0.8138	0.4534	2.80***
Education	0.1119	0.0651	0.0240	1.81**
Active family labor (AE)	0.0259	0.0587	0.0056	0.44
Number of oxen	0.1344	0.1287	0.0289	1.03
Land total	0.1227	0.0694	0.0263	1.87**
Year sesame	0.0346	0.0298	0.0074	1.18
Income livestock	0.0360	0.0230	0.0077	1.61
Food availability	0.8634	0.5137	0.1854	1.76*
Credit access	0.9770	0.4784	0.2098	2.20**
Social capital	− 0.7064	0.5037	− 0.1517	− 1.45
Selling channels	0.5314	0.5842	0.1141	0.91
_cons	− 8.8741	2.5346		0.00
/sigma	1.6104	0.2418		0.00
Mean dependent var		0.902	SD dependent var	0.914
Number of obs		281	Chi-square	24.615
Prob > Chi2		0.055	Akaike crit. (AIC)	477.502

*** p < 0.01, ** p < 0.05, * p < 0.1

Conclusion and policy implications

Climate change has become increasingly recognized as a global phenomenon with widespread adverse impacts on food and water security, human health, economies, society and related losses and damages to nature and people. This study examined implication of climate change and adaptation strategies for sesame production and household food security in Western Ethiopia. For this purpose, food security index constructed based on HFIAS was used as a dependent variable and 2SLS estimation framework was employed to estimate food security model. We examined factors affecting the level of sesame production, conditional on participation decision, which was implemented using the double-hurdle (D-H) model. The trend analysis of annual mean temperature and rainfall indicated that farm households in study area have faced climate change and variability. In response the farmers have been adapting to it using different strategies like agronomic practices (36.25%), livelihood diversifications (26.50%), soil and water conservation (21%) and small-scale irrigation (12.75%). Though sesame production has been negatively impacted by climate changes, this study revealed that smallholders have kept sesame production mainly due to its high value crop character.

Additionally, the study results from the two-stage least square (2SLS) estimation showed that increases in temperature and rainfall variability have significant negative impact on household food security. More specifically, one unit change in temperature can lead to 3.34, 8.25 and 1.23 percent deterioration of household's food security position under agronomic practices, livelihood diversifications and irrigation adaptation scenarios. Favorable rainfall condition has positive and statistically significant impact on food security. It significantly improves household's food security position by 39.11% under agronomic practices and 27.85% under small-scale irrigation scenarios Furthermore, results showed that climate adaptations have positive impact on household food security. Adaptation measures like agronomic practices, small-scale irrigation, and soil and water conservation have significant positive impact on household food security. For instance, adaptation of agronomic practice improves food security status by about 32% while SWC improved it by nearly 27%. Similarly, estimation from truncated model reveals that adaptation strategies have positively and significantly impacted level of sesame production. Adoption of agronomic practices, livelihood diversification and soil and water conservation strategies have improved the level of sesame production. Households who adopt agronomic practices like crop diversification, using drought-tolerant and modern varieties brings 0.17 hectare more land in to sesame production. This suggests that adaptation strategies are effective both in ensuring household food security and improving level of sesame production.

These findings call in policy and programs to further promote the adoption of climate-change adaptation options based on the households' adaptive capacity. As rainfall variability is a critical constraint to household food security, risk reducing measures and programs would be helpful. The results highlight the importance of awareness and knowledge about adaptation options and its risk reducing potential. Hence, policy should target increasing provision of relevant timely information on current as well as future climate forecasts, introducing modern high yield and climate resilient crop will enhance farmers' climate adaptation decisions and help in reduce food insecurity in one hand and boost sesame production on the other hands.

This study provided good insights on the impact of adaptation on both food security and sesame production. We examined the aggregate impact of different adaptation practices; however, it would be imperative if future research examine the disaggregated impacts of each adaptation options on household food security and level of sesame production in the study areas. Further, the study was based on data collected from the sample household survey during a single cropping season using a cross-sectional data, and hence theoretical analyses of this research are largely static. In this case production, adaptation and adoption decision process are treated as a static phenomenon and issues of expectations and dynamic adjustments would be overlooked. Although incorporation of dynamics and expectations into tractable models is important for the foreseeable future, the dynamic model avenue was not included in this research. It would be imperative if future research take on this broad venture.

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Author contributions

GMD is the principal author of this study. He initiated the proposal, developed the survey questionnaire, coordinated and supervised the fieldwork for data collection, conducted the data management and analysis and wrote the manuscript. EFL has provided support during the questionnaire development, data collection and management and manuscript write-up. Both authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
The authors give consent to the *Journal of Agriculture and Food Security* to publish and distribute this paper under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Competing interests
The authors declare that they have no competing interests.

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